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13. ABSTRACT (*Maximum 200 words*)

THE PROPOSAL IS SUBMITTED IN RESPONSE TO A VERBAL REQUEST FROM THE U.S. ARMY MEDICAL RESEARCH & DEVELOPMENT COMMAND. THE PROPOSED PROGRAM IS A CONTINUATION OF THE WORK BEGUN UNDER CONTRACT DAMD-17-75-C-5069. A PORTION OF THE PROPOSED EFFORT IS UNINTERRUPTED CONTINUATION STUDIES OF EXPERIMENTS CURRENTLY UNDERWAY (E.G, PLANT GROWTH & DIMP LYSIMETER TYPE) & THE REMAINING PORTION IS WORK TO BE INITIATED (E.G., DCPD LYSIMETER STUDIES). CURRENTLY A SELECT GROUP OF PLANTS ARE BEING EXPOSED TO DIMP & DCPD IN A SOIL CULTURE SYSTEM TO DETERMINE THEIR EFFECTIVE LEVELS AS TO PHYTOTOXICITY & BIOACCUMULATION IN THIS GROWTH MEDIUM. COMPLETION OF THIS TASK, AS WELL AS THE UTILIZATION OF SEEDS FROM THIS TASK IN FURTHER STUDIES, ARE INCLUDED IN THE PROPOSED EFFORT. A SECOND AREA OF STUDY CURRENTLY UNDERWAY, & TO BE CONTINUED, RELATES TO THE MANNER IN WHICH THE CONTAMINANT COMPOUNDS MIGRATE THROUGH SOIL.

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DETERMINATION OF DECONTAMINATION CRITERIA
DIMP AND DCPD

to

U.S. Army Medical Research and
Development Command

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AEROJET ORDNANCE AND MANUFACTURING COMPANY

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8800-46-1600

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Section 1

INTRODUCTION

This proposal is submitted by Aerojet Ordnance and Manufacturing Company (AOMC) in response to a verbal request from United States Army Medical Research and Development Command. The proposed program is a continuation of the work begun under Contract DAMD-17-75-C-5069. A portion of the proposed effort is uninterrupted continuation studies of experiments currently underway (e.g., plant growth and DIMP lysimeter type) and the remaining portion is work to be initiated (e.g., DCPD lysimeter studies).

AOMC feels that it has a unique background which qualifies it to undertake this effort. This background consists of 19 years of direct study in CW agent generation, decontamination, and detection, plus the study of agent mobility in soil and plants on several classified contracts and in the first year of this study.

To ensure continuity of effort, the facilities and personnel who have been conducting the early phase of this study will be made available to continue the program in an uninterrupted manner.

Section 2

STATEMENT OF WORK

AOMC will provide the necessary personnel, facilities, equipment, and materials to perform the proposed 12-month program. The proposed program tasks are shown in Figure 1 and are discussed in the following paragraphs.

2.1 TASK 1 -- PROTOCOL TASK III PART 1 SOIL CULTURE EXPERIMENTS

This task is the completion of plant growth in soil culture tests begun under Contract DAMD-17-75-C-5069 to determine the uptake and bioaccumulation of DIMP and DCPD and resultant phytotoxicity symptoms.

2.2 TASK 2 -- PROTOCOL TASK III PART 2 SOIL CULTURE EXPERIMENTS

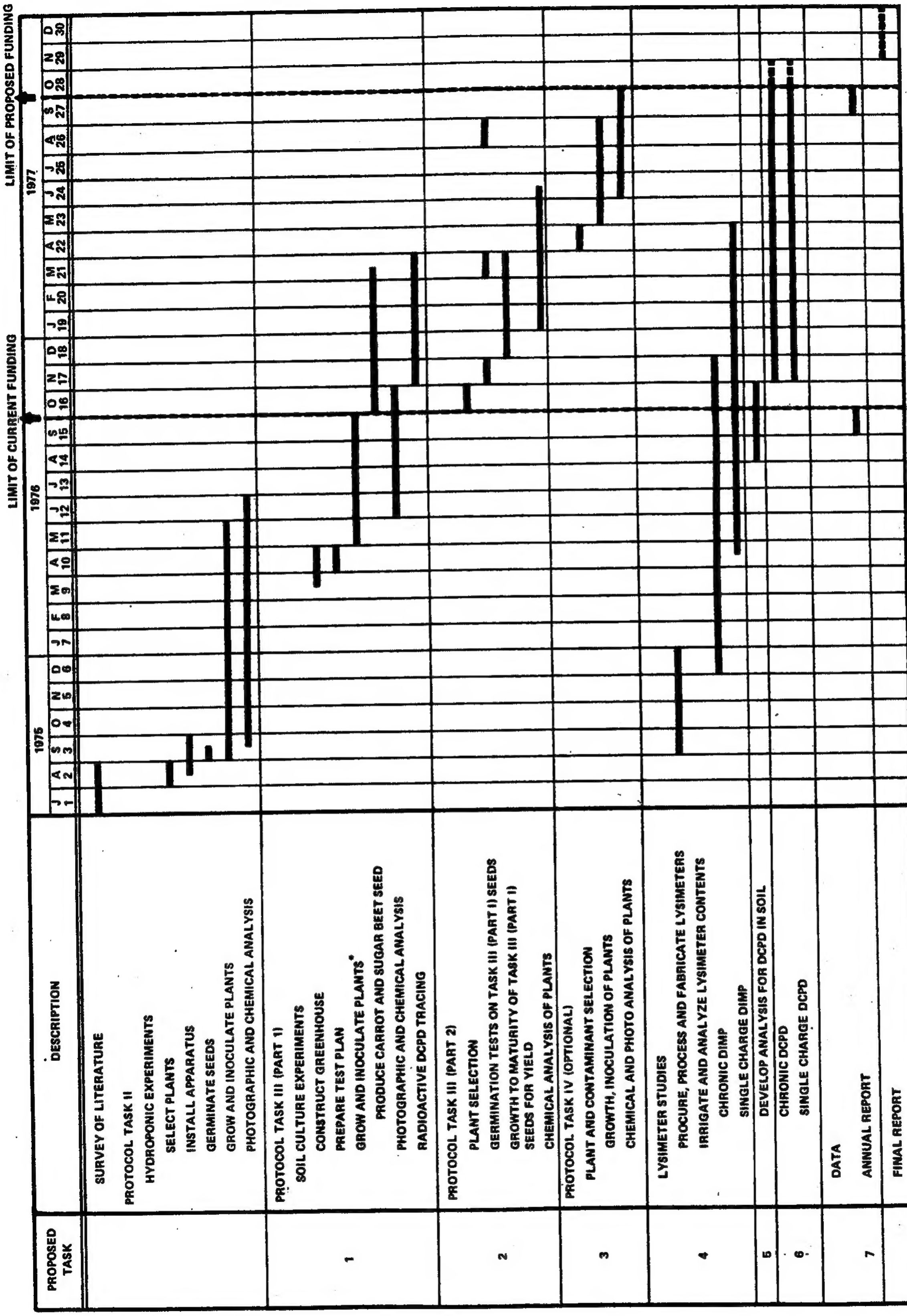
AOMC proposes to conduct germination tests on a selected group of seeds from plants in Task 1, and a test group will be grown to maturity for yield data and agent carry-over analyses.

2.3 TASK 3 -- PROTOCOL TASK IV (OPTIONAL) MULTIPLE COMPOUND EVALUATIONS

Subject to the outcome of preceding tasks a determination will be made of synergistic or antagonistic effects of combined contaminants (e.g., DIMP and DCPD) as to bioaccumulation and phytotoxicity.

2.4 TASK 4 -- DIMP SOIL RETENTION EXPERIMENTS

The chronic exposure and single charge DIMP lysimeter experiments will be carried to equilibrium (12-months treatment) in five different types of soil each.



*POSSIBLE SLIPPAGE POINT. ADJUSTMENT OF CONTAMINANT AT THIS POINT SHIFTS ALL FOLLOWING PLANT WORK TO THE RIGHT.

Figure 1. Determination of Decontamination Criteria -- DIMP and DCPD Research Task Schedule.

2.5 TASK 5 -- DEVELOP ANALYSIS FOR DCPD IN SOIL

Studies will be pursued to develop a quantitative method of analysis for DCPD in a soil matrix in parts per million concentrations.

2.6 TASK 6 -- DCPD SOIL RETENTION EXPERIMENTS

Subject to the outcome of Task 5, a 12-month lysimeter study of the mobility of DCPD in the five types of soil used in Task 4 will be performed both with chronic and single charge exposures.

2.7 TASK 7 -- DATA

AOMC will deliver informal monthly progress reports and a formal annual summary report at the conclusion of the program.

Section 3

TECHNICAL DISCUSSION

3.1 PROBLEM BACKGROUND

The operation, test, storage, and/or demilitarization of chemical warfare material has resulted in the insertion of chemical compounds into the environmental system which can have deleterious effects. Previous work established that DIMP (diisopropyl methyl phosphonate) and DCPD (dicyclopentadiene) are present in Rocky Mountain Arsenal soil and water samples. These compounds, when introduced in sufficient concentration, produced phytotoxic effects in growing plants. Also, it was demonstrated that plants have the ability to accumulate contaminant compounds in various portions of their structure.

AOMC work performed under Contract DAMD-17-75-C-5069, under the sponsorship of the U.S. Army Medical Research and Development Command, demonstrated that DIMP produced both phytotoxicity and bioaccumulation when introduced into both hydroponic and soil culture systems for a series of plants. Phytotoxicity was demonstrated in the case of DCPD in a similar group of plants hydroponically grown. Currently, a select group of these plants is being exposed to DIMP and DCPD in a soil culture system to determine their effective levels as to phytotoxicity and bioaccumulation in this growth medium. Completion of this task, as well as the utilization of seeds from this task in further studies, are included in the proposed effort.

A second area of study currently underway, and to be continued, relates to the manner in which the contaminant compounds migrate through soil. This migration, if occurring at a slow enough rate, would not subject the surrounding area to a practical hazard and, conversely, if at a rapid enough rate, would affect the surrounding area. It has been shown in current lysimeter experiments that DIMP contaminants do move through the various types of soils studied. During the proposed follow-on study this movement will be quantitated and a similar study will be run on DCPD in soil.

Some of the technical procedures and examples of the data output from the current study are discussed in the following paragraphs.

3.2 PLANT UPTAKE

3.2.1 Hydroponic Systems

Standard hydroponic apparatus (Figure 2), operated as described in Reference 1, was used in the initial plant growth studies. Ten different species of plants were treated with four concentration levels of contaminant; i.e., 1 ppm, 10 ppm, 100 ppm, and 1000 ppm. Duplicate experiments were run with DIMP and DCPD. In the case of the DIMP, phytotoxic effects were quickly found in the 1000 ppm case. In most cases the lower two concentrations of DIMP had an enhancing effect on the plant growth while the higher two concentrations of DIMP had a negative effect. With DCPD the effect was generally negative with concentration. An example of this type of information is shown in Table 1 and in Figures 3 and 4 for yield of radish plants. The bioaccumulation factors (agent concentration in fresh picked plant ÷ agent concentration in nutrient bath) for the DIMP specimens from Figure 3 are shown in Table 2 and Figure 5.

The bioaccumulation of DIMP in the various plant parts is shown dramatically in Table 3 for plants which were exposed to 1000 ppm DIMP in nutrient for only 2 to 3 weeks. At this time all of the plants except the juniper were severely necrotized.

The DIMP had higher accumulation in the leaves of the plants than in the stems or roots. Generally, the accumulation increased rapidly in the first few weeks of growth and then fell off gradually as the plant aged. Figure 6 shows these data for tomato leaves. Similar curves for bioaccumulation factors of varying magnitude were found for the other species tested.

Because of this positive indication of bioaccumulation and phytotoxicity in plants, a series of tests were planned in which a select group of these plants were to be grown in soil culture and irrigated with distilled water which contained varying concentrations of DIMP and DCPD. One purpose of these tests was to determine the similarity in reaction of the plants to contaminants in soil irrigation as opposed to flowing over their roots continually in a hydroponic bath. When originally applied to the soil the irrigation water will have a given concentration. Immediately surrounding the plant root, assuming the plant accumulates the contaminant compound, the concentration of contaminant will dimish. Water and contaminant must then flow into this area from the surrounding soil and the concentration of this water can be diminished by agent adsorption on the soil, chemical degradation of the agent catalyzed by soil components, evaporative changes in concentration, and

*"Determination of Decontamination Criteria for Demilitarized Chemical Warfare Installations," Proposal No. DP-75V231, AOMC, June 1975.

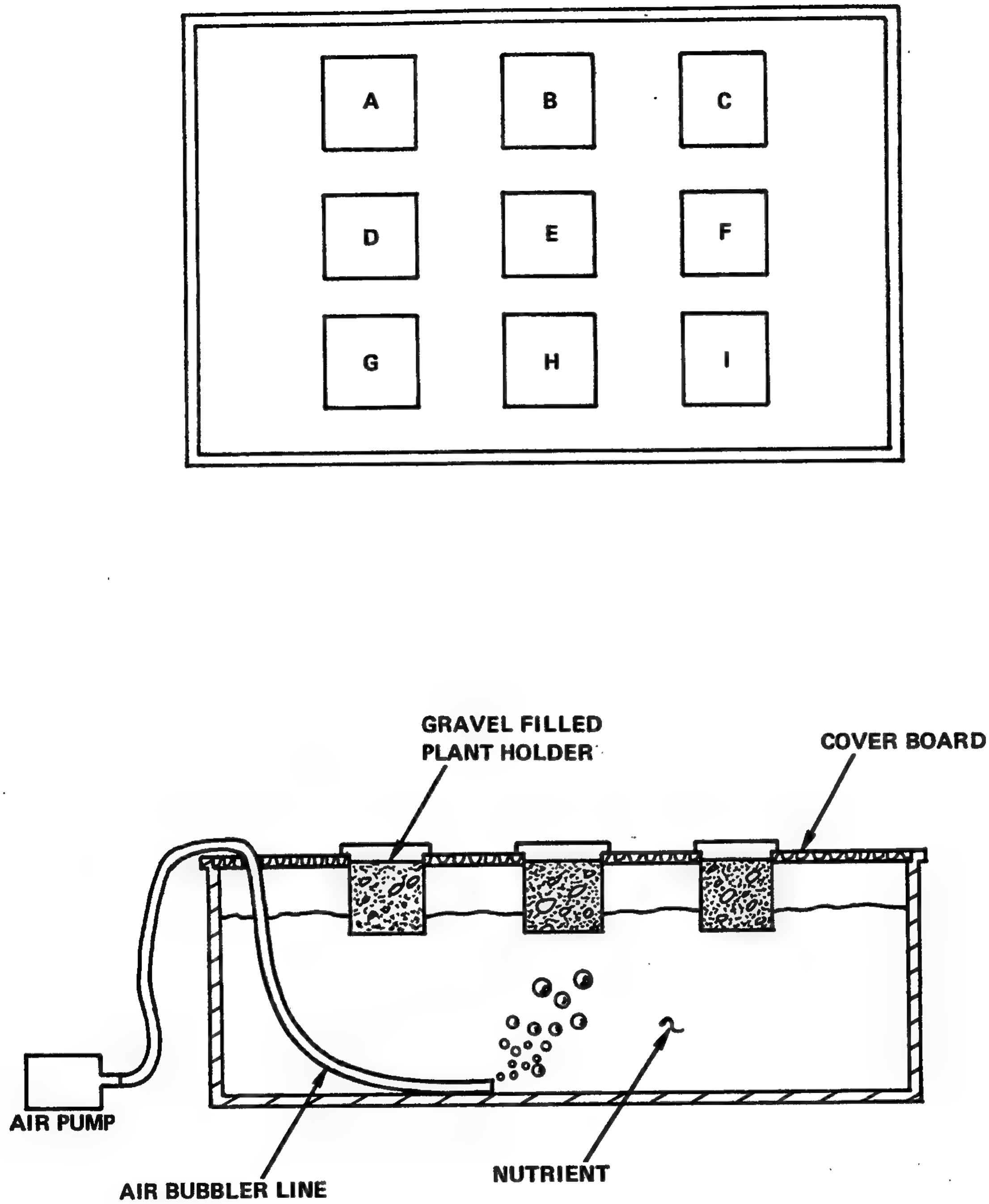


Figure 2. Setup of Hydroponic Baths for Range Finding Experiments.

Table 1. Yield of Radish Plants from Various Nutrient Levels of Contamination.

Type and Level of Contamination	Weight of Plant Part (gm)		
	Root	Fruit	Leaves
DIMP			
Control	5.2	43.1	16.7
1 ppm	0.8	51.2	14.4
10 ppm	3.2	82.2	32.8
100 ppm	1.7	24.3	9.9
1000 ppm	0.05	0.13	0.29
DCPD			
Control	2.0	74.6	30.8
1 ppm	2.3	58.8	20.5
10 ppm	1.2	66.4	21.2
100 ppm	0.6	30.7	11.0
1000 ppm	1.2	17.6	12.5

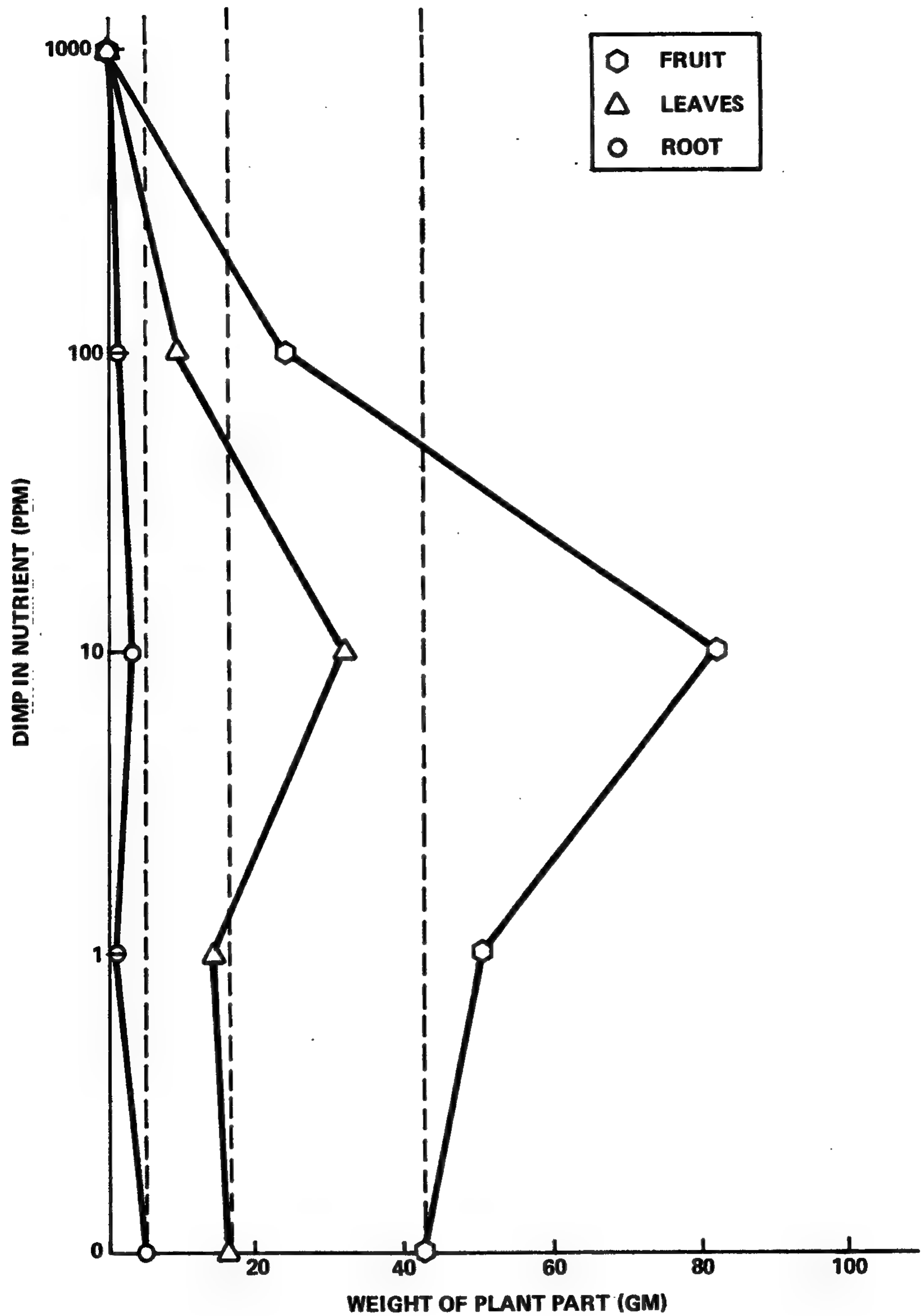


Figure 3. Yield of Radish Plants from Various Nutrient Levels of DIMP Contamination.

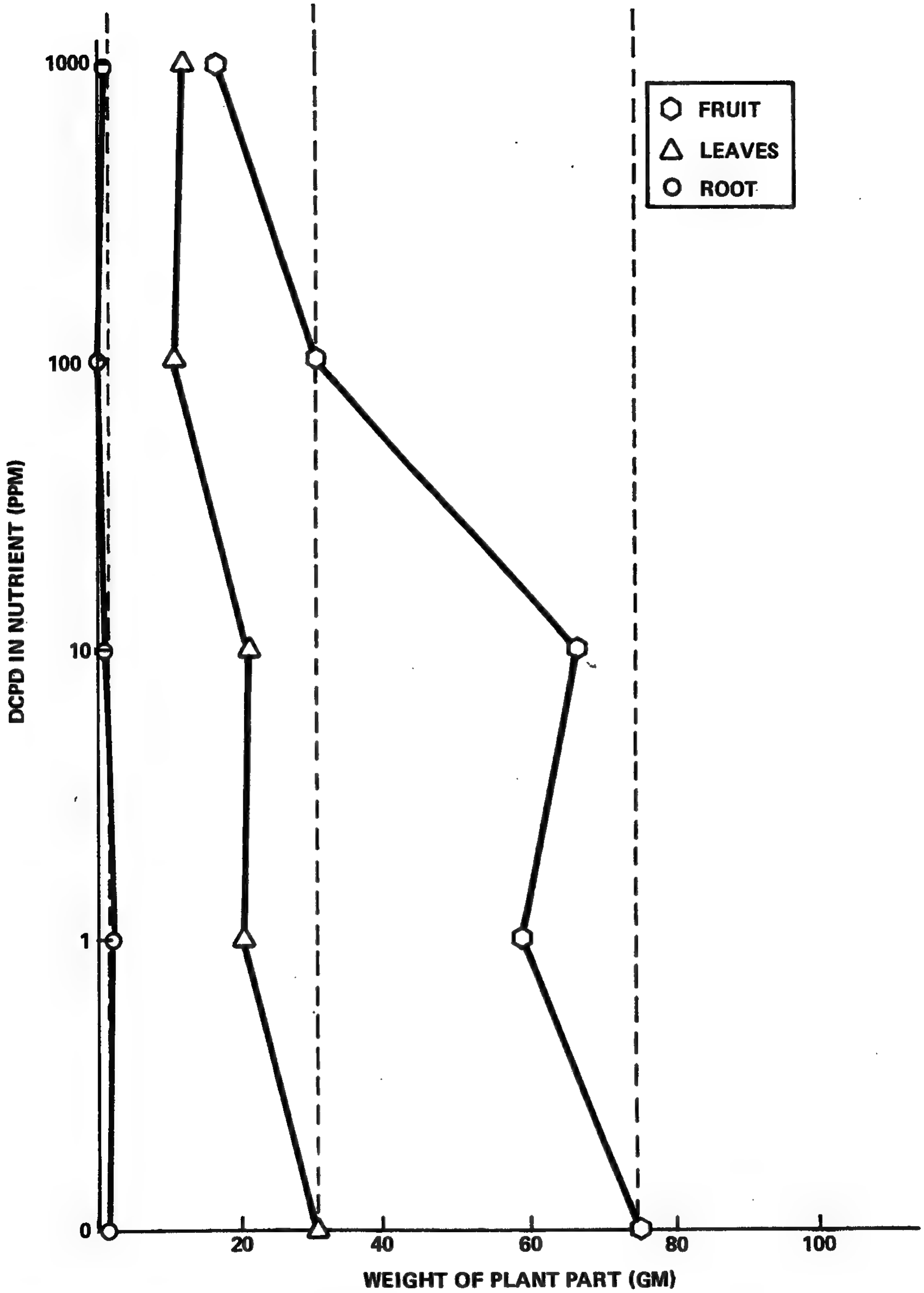


Figure 4. Yield of Radish Plants From Various Levels of DCPD Contamination.

Table 2. DIMP Content of Radish Parts After 28 Days Exposure.

Plant Part	Concentration of DIMP in Nutrient (ppm)	Concentration of DIMP in Plant (ppm)	Bioaccumulation Factor
Leaf	1	12.05	12X
Leaf	10	48.3	4.8X
Leaf	100	957.6	9.6X
Leaf*	1000	5231	5.2X
Fruit	1	0.3	0.3X
Fruit	10	7.3	0.7X
Fruit	100	175	1.8X
Fruit*	1000	1000	1.0X
Root	1	2.3	2.3X
Root	10	9.7	1.0X
Root	100	109	1.1X
Root*	1000	2935	2.9X

*22 days exposure

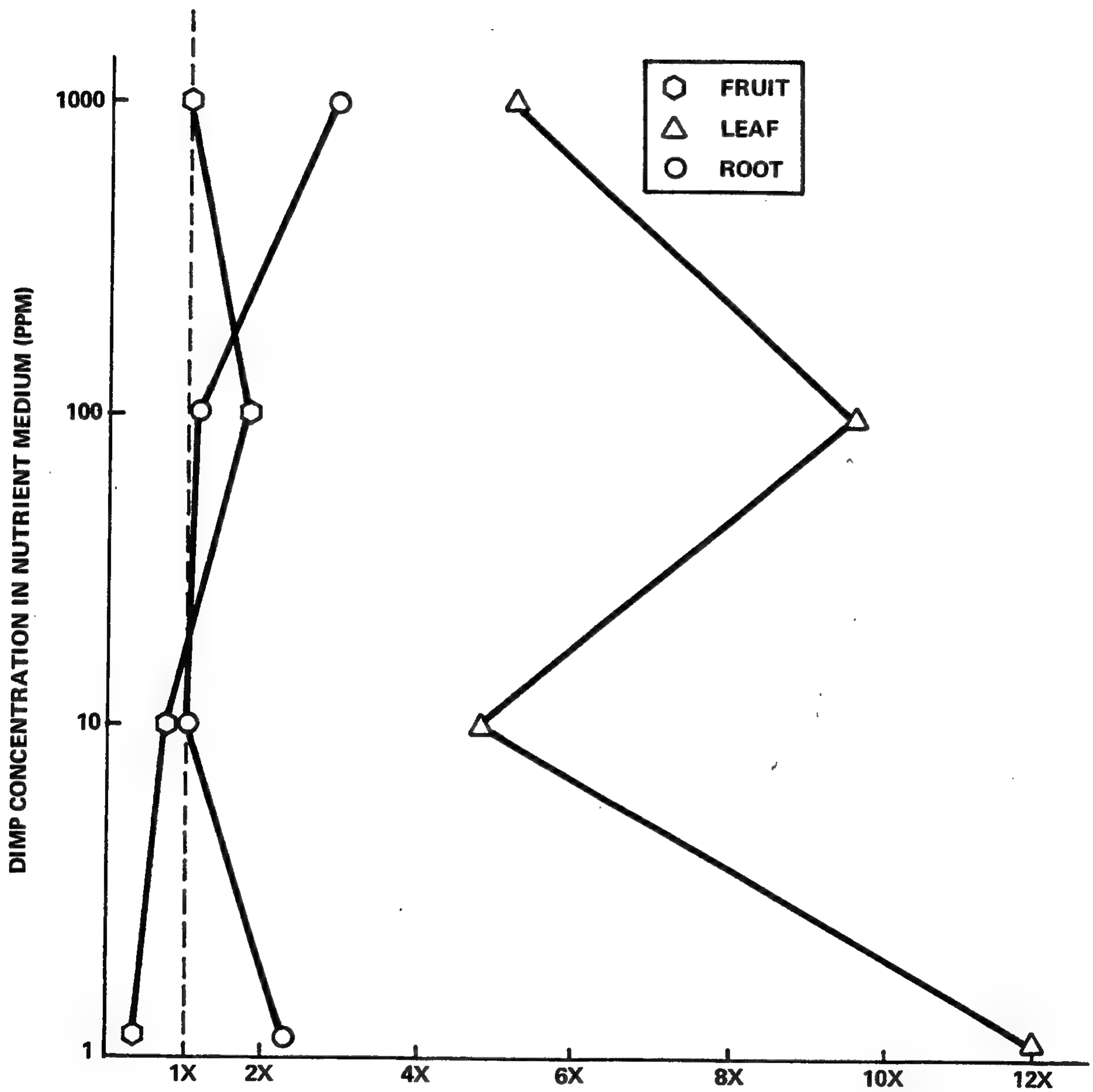


Figure 5. Bioaccumulation of DIMP in Radish Parts at Maturity.

Table 3. DIMP Content of Plant Parts (from 1000 ppm Nutrient, 22-25 days exposure).

Plant Type	Leaves (ppm)	Stem (ppm)	Root (ppm)
Tomato*	15,213	3040	4674
Corn	8,918	8993	1703
Bean	8,000	2018	729
Radish	5,231	1000	2935
Fescue	2,329	134	208
Sugar Beet	1,851	208	30
Carrot	1,137	541	52
Rose	613	42	136
Wheat	192	**	3
Juniper	53	**	**

*15 days

**Not processed

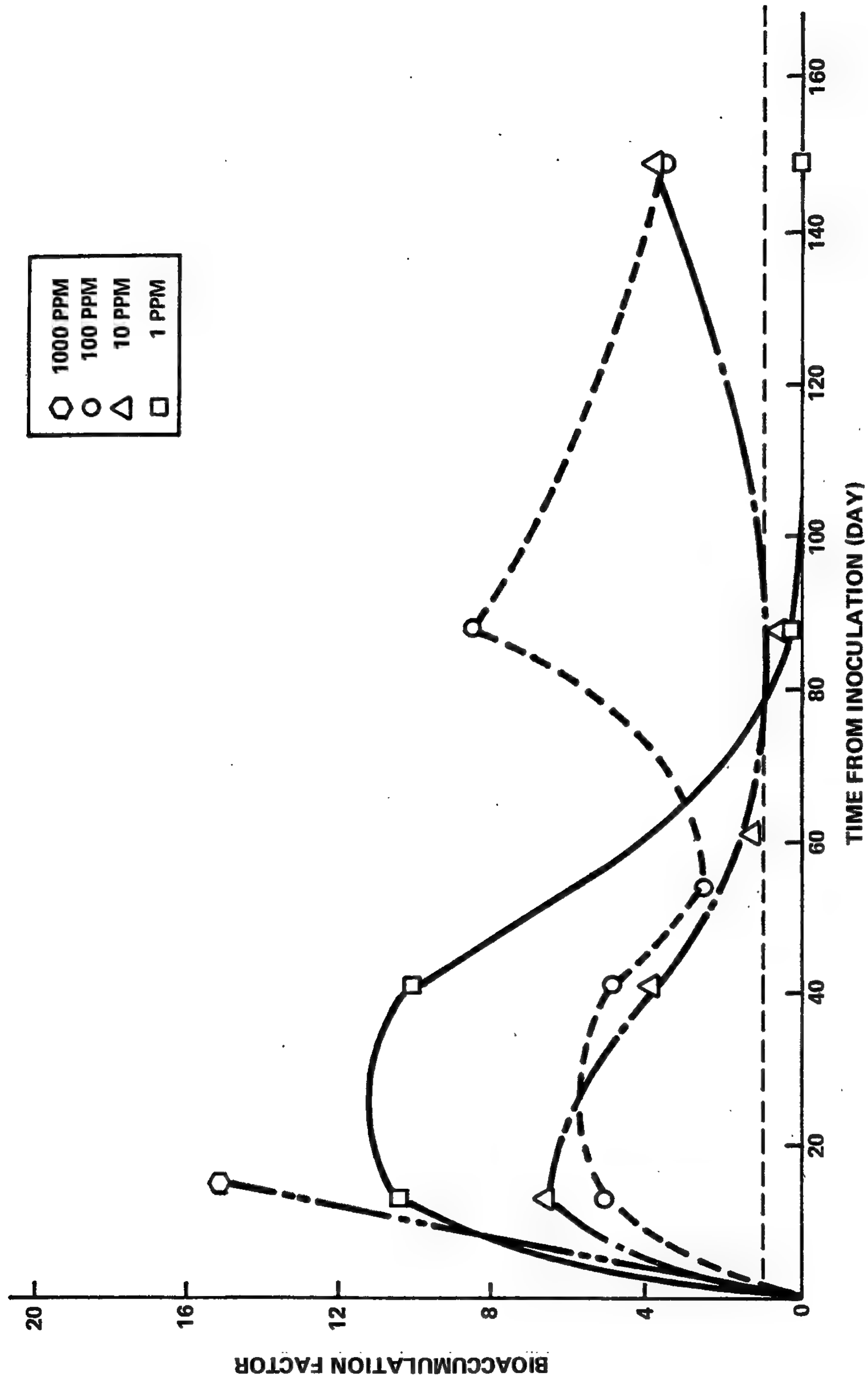


Figure 6. Bioaccumulation of DIMP in Tomato Leaves.

microbial action. The extent of the effect of these various mechanisms is not known but will be reflected in the growth patterns, chemical assay, and state of health of the plants.

The initial testing was begun with one, eight, and twenty parts per million of contaminant in the irrigation water. If these concentrations prove to be too low to provide a demonstrable effect on the plants, a new group will be inoculated at a higher concentration. It is expected that this experiment will be somewhat advanced by the end of the current program and will be completed during the coming year.

The soil culture experiments are being performed in a 14- by 42-ft greenhouse constructed during the current effort (Figure 7). An interior view of one of the house's three rooms with the seeded plant containers is shown in Figure 8. Preliminary results from plant tissue analyses show that DIMP is accumulated in the plant parts. The DCPD has not been shown to be so accumulated. These experiments should be completed during the coming follow-on period.

A determination of the deposition of DCPD in plant parts will be made with radioactive techniques after the effective level of contamination has been determined by soil growth studies. One approach to the location of the radioactive compounds is illustrated in Figure 9, which is a photograph of a leaf of a bean plant which has been hydroponically grown in a nutrient solution containing a radioactive phosphorous organic compound. This photograph is compared with an autoradiograph of the same leaf, which was made by pressing it against a 3000-speed Polaroid film-pak for several days and subsequently developing the film. Plant parts thus identified as containing the radioactive DCPD can then be subjected to quantitative scintillation analysis for DCPD content.

3.3 LYSIMETER STUDIES

The lysimeter studies of DIMP migration underway on Contract DAMD-17-75-C-5069 will continue and similar studies concerning DCPD will be commenced.

The first activity relating to the DCPD is the development of a quantitative and sensitive extraction and analysis procedure for DCPD in soil. The analysis in water and in plant tissue has been developed to the extent that 1 ppm can be quantitatively recovered from these matrixes. These analyses consist of methanolic extraction of the plant tissue followed by partitioning

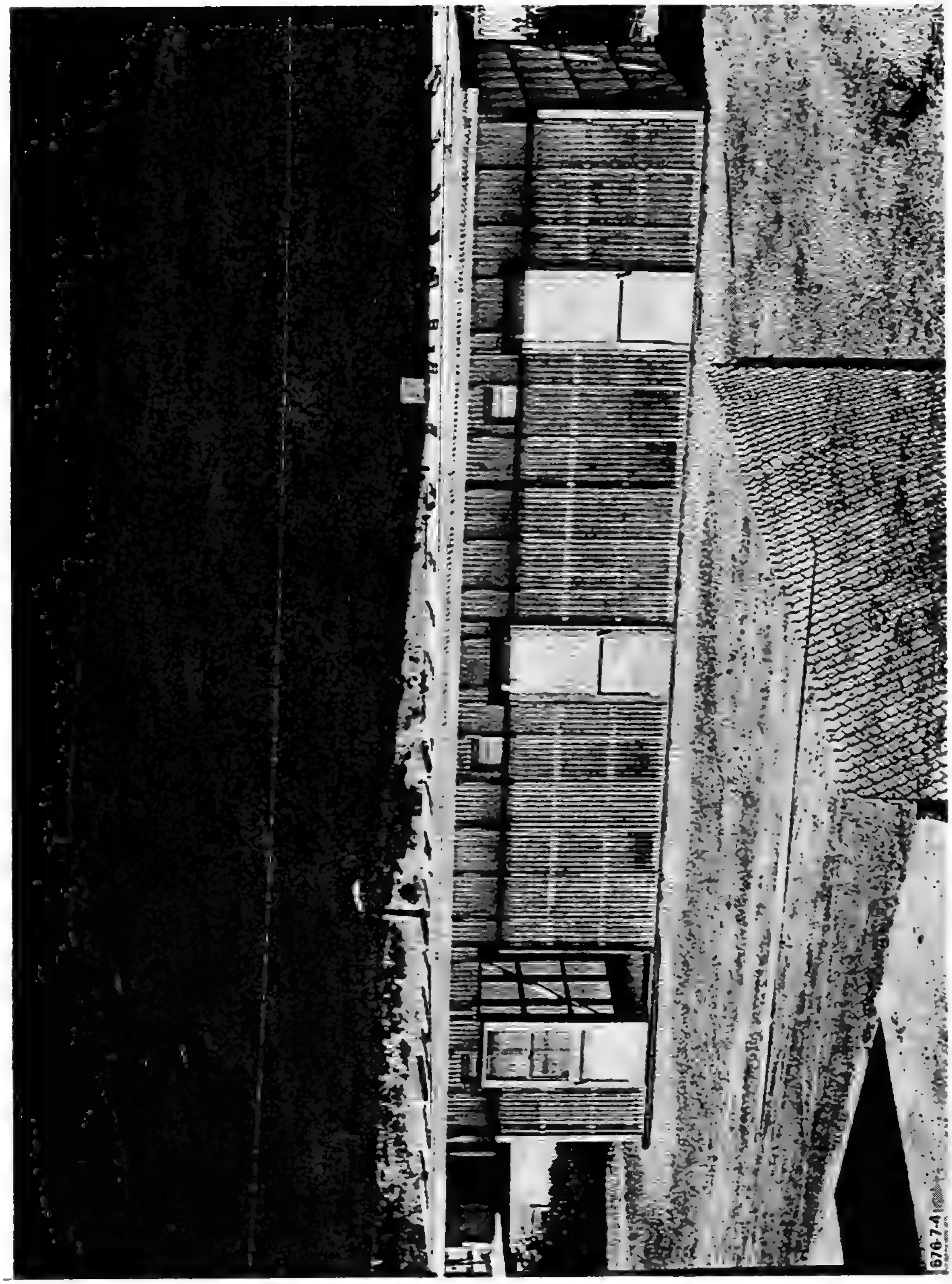
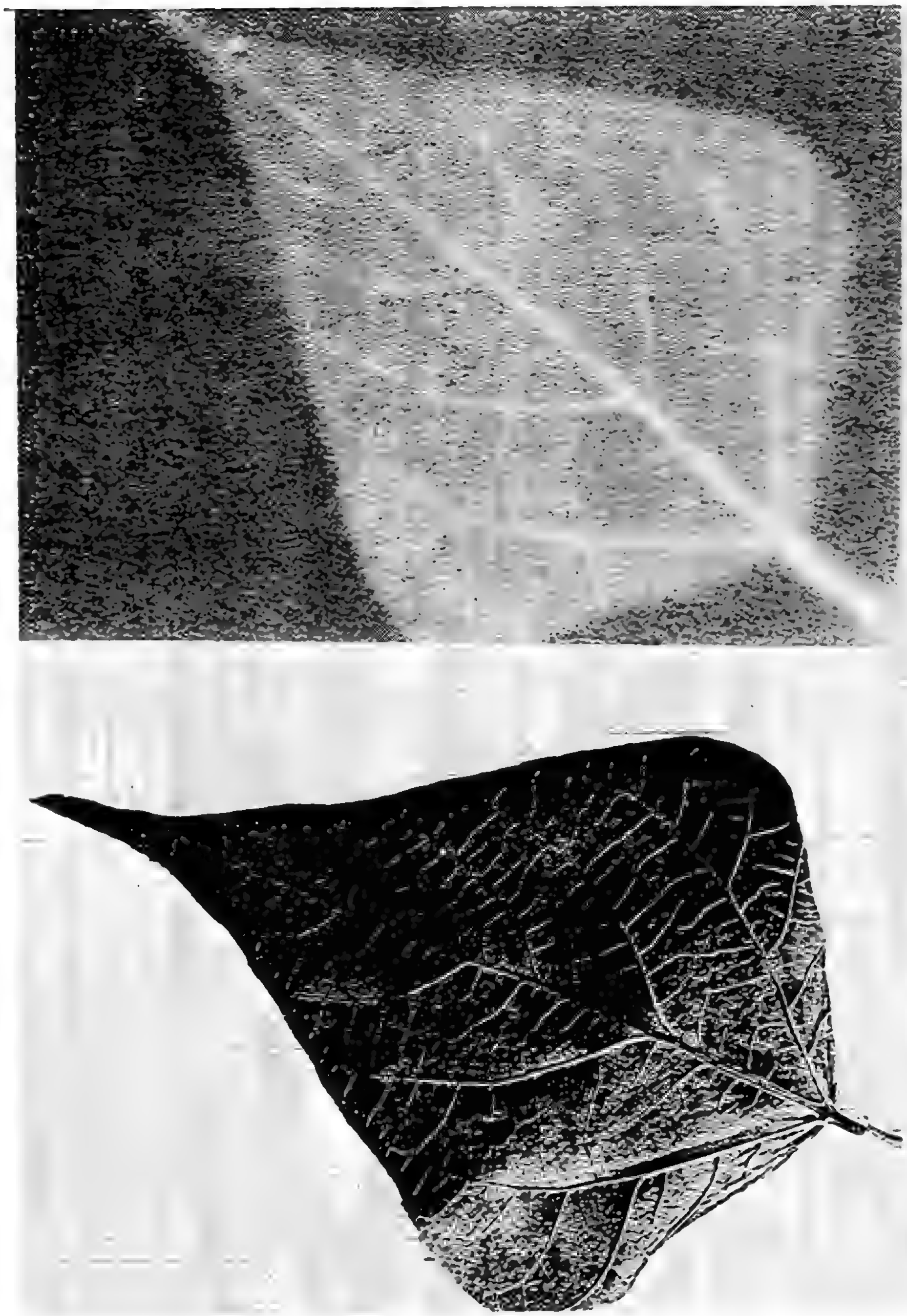


Figure 7. Soil Culture Greenhouse.

Figure 8. - Soil Culture Containers -- DIMP Room.



Young Leaf (Photograph)

Young Leaf (Autoradiograph)

Figure 9. Autoradiograph of Leaf from Plant Treated with ^{32}P.

procedures which result in a solution of the DCPD in carbon disulfide which is then subjected to gas-liquid chromatographic techniques (GLC). The water analyses are run by simply extracting the water with carbon disulfide and chromatographing (GLC) the carbon disulfide solution. A more elaborate extraction procedure appears to be necessary for the soil samples and a study of these will be commenced during the current contract.

The soils used in the lysimeter studies represent a range of soil types. Soils can be classified by several different methods, most of which are related to the soil's relative suitability for raising crops. In selecting specific soils for controlled laboratory experiments, the physical and chemical properties are the most important classification criteria. A typical soil contains approximately 50% solid matter by volume, 25% water, and 25% air. The solid matter is usually 1% to 20% organic material, with 80% to 99% inorganic minerals. Variations in the particle size distributions of the inorganic mineral particulates give soil its basic texture. Particles are grouped into the following sizes for soil classification:

Particle Diameter	Class
0 to 2μ	Clay
2 to 50μ	Silt
50 to 100μ	Fine sand
100 to 500μ	Medium sand
500 to 2000μ	Coarse sand
2mm to 3 in.	Gravel
Over 3 in.	Stone

The actual analyses of soils used in current lysimeter tests at AOMC (Table 4) are superimposed on the classification plot in Figure 10. A spectrographic analysis of the same soils (Table 5) completes these characterizations.

In summary, the soils of interest are a sandy clay loam (Chino), a silty clay (Brawley), a clay loam (Ventura), a sandy loam (Fullerton), and slightly different clay loam (Walnut). All of these soils were procured within the State of California at the geographical locations shown in Figure 11 and were characterized in the laboratory.

Table 4. Characterization of Lysimeter Sample Soils.

Soil Source	pH	Organic Matter (%)	Sand (%)	Silt (%)	Clay (%)	Moisture Capacity (%)	Exchange (pH 7) Capacity (me/100gm)
Chino	5.6	3.7	49	26	25	45.4	18.5
Brawley	7.9	0.9	16	25	59	49.8	28.9
Ventura	7.1	1.9	31	42	28	45.1	18.2
Fullerton	6.9	2.2	60	22	18	44.5	16.6
Walnut	6.9	4.1	32	33	34	56.5	37.8

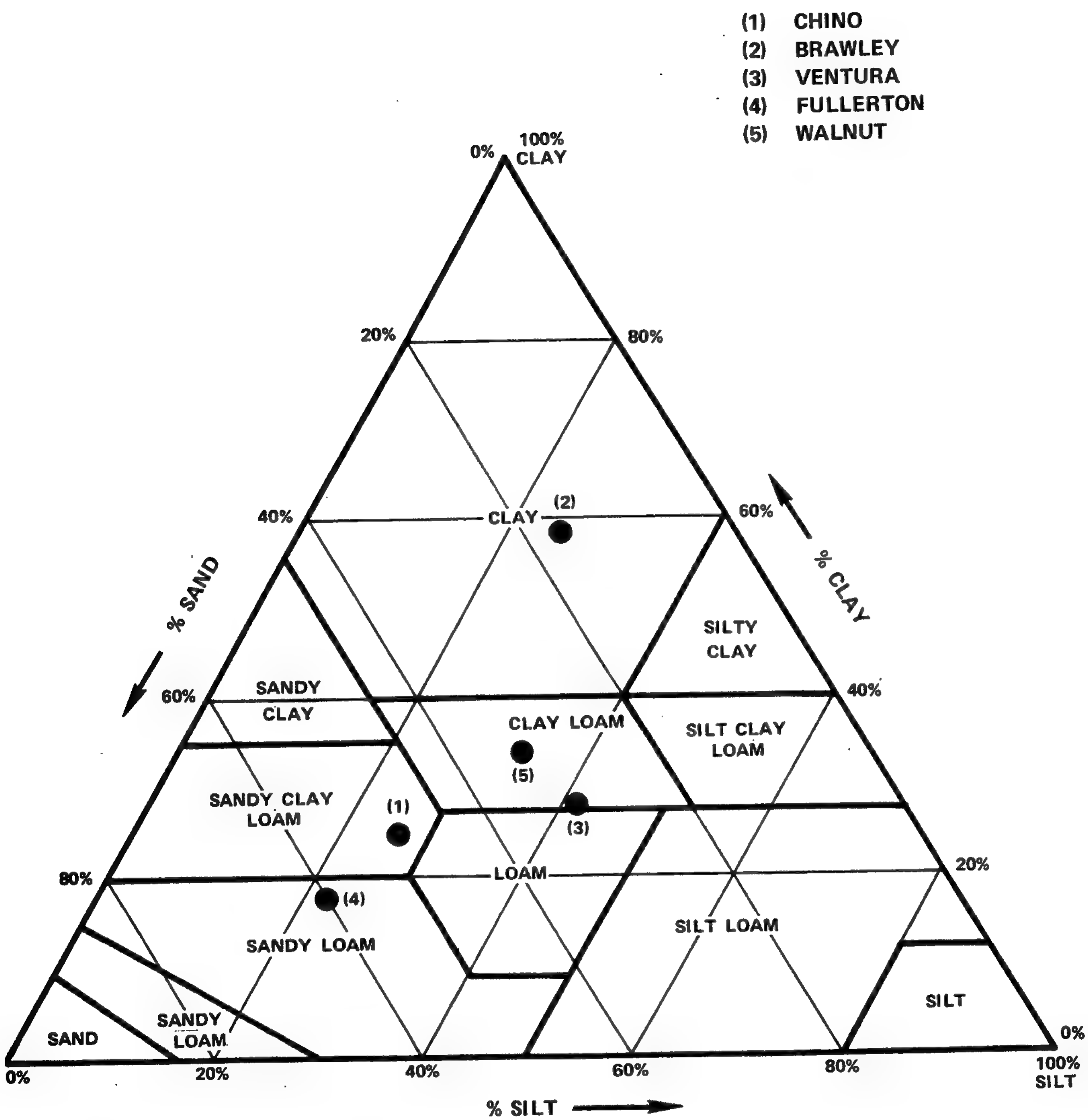


Figure 10. Textural Classification of Soils.

Table 5. Spectrographic Analyses of Top Soil Samples.

Element	Semiquantitative Analysis (%) Brawley	Chino	Fullerton	Ventura	Walnut
Si	23.0	30.0	33.0	28.0	28.0
Al-	11.0	8.5	5.5	8.8	8.7
Fe-	3.3	2.5	2.0	2.4	3.6
Ca-	5.3	2.0	2.4	1.4	2.8
Mg	1.6	0.85	0.69	1.2	1.5
Na-	3.2	4.5	4.5	7.4	5.2
K-	3.7	1.7	2.5	2.9	1.9
Ba-	TR<0.05	0.052	0.054	0.053	0.079
B-	0.0042	ND<0.003	ND<0.003	TR<0.003	ND<0.003
Ti-	0.50	0.42	0.27	0.53	0.57
Pb-	TR<0.01	TR<0.01	TR<0.01	TR<0.01	TR<0.01
Ga-	0.0068	0.0039	0.0032	0.0048	0.0061
Mn-	0.050	0.059	0.055	0.040	0.063
V-	0.0094	0.0084	0.0076	0.0092	0.0087
Cu-	0.0042	0.0030	0.0049	0.0067	0.0059
Ag-	ND<0.0001	ND<0.0001	TR<0.0001	ND<0.0001	ND<0.0001
Ni-	0.0034	0.0032	0.0031	0.0044	0.0046
Zr-	0.021	0.025	0.025	0.039	0.028
Co-	0.0028	0.0023	0.0021	0.0024	0.0040
Cr-	0.035	0.013	0.027	0.054	0.032
Sr-	0.0020	0.0023	0.0021	0.0022	0.0019
Other	Nil	Nil	Nil	Nil	Nil

TR = Trace

ND = Not detectable

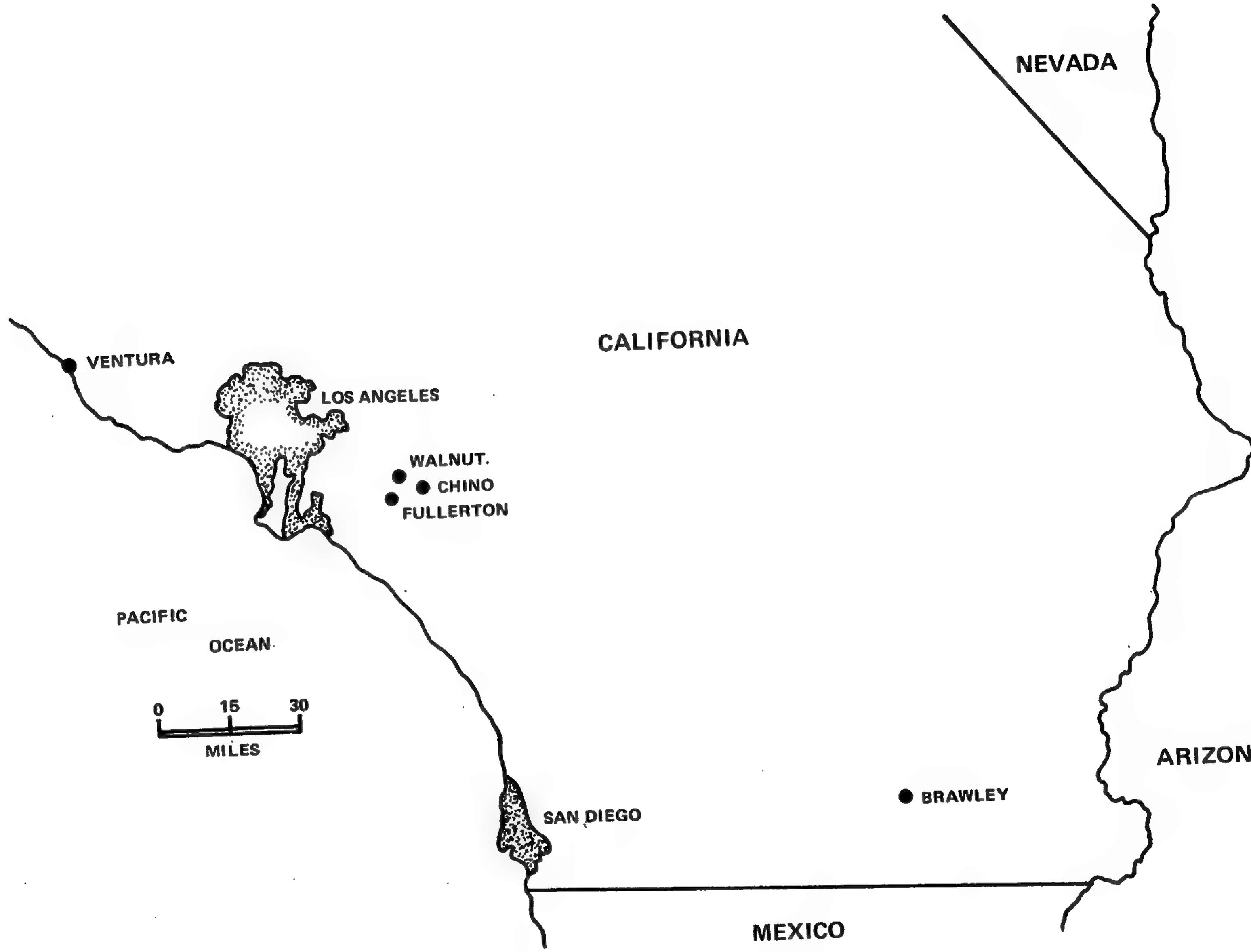


Figure 11. Geographic Location of AOMC Lysimeter Samples.

In conjunction with AOMC's soil consultant from the University of California, Riverside, we concluded that the required soil types could be obtained within the State and were able (with the cooperation of several private and Governmental organizations) to obtain enough samples for the lysimeter loading.

Another basic ingredient in the performance of this type of experimentation is the design and construction of the lysimeters. The lysimeters currently used at AOMC consist of two 55-gal drums welded end to end with all but one end removed and the interior coated with epoxy paint. The drums are fitted, through holes in the sides and bottom, with tensiometers for collection of groundwater samples. The soil of any particular type, which was removed from its original location in 1 ft depth increments, is dried, screened, and repacked into the lysimeter to duplicate its profile in the earth. Figure 12 shows a bank of 10 lysimeters with tensiometers attached and in operation. Each lysimeter has its own screened top that is removed for access while sampling soil or adding water. Figure 13 is a 3 ft length of tensiometer tubing with the ceramic sampling adapter welded to the inner end. Construction sketches of the lysimeter stand and cover are shown in Figures 14 and 15.

The bulk of added water, by far, is sampled out the bottom of the lysimeter. A term designated as drainage efficiency (volume of water put in the lysimeter divided by the volume of water sampled out the bottom) has been used to follow the throughput of the water. Since some soils, e.g., the Fullerton sandy loam, will not pass the water rapidly enough for a 2-in. per week addition rate, the rate has been altered. Figure 16 shows the drainage efficiencies for the first several months of this study.

Because of the high specific surface area of the smaller clay particles, soil containing high clay fractions is much more absorbent than sandy soils. Clay soils retain water and remain moist for long periods. In addition to the soil's physical properties, presence of soluble minerals determine the salinity, alkalinity, and chemical reactivity; the alkalinity can have a critical effect on the decomposition kinetics of chemicals applied to the soils. The inorganic mineral particles are primarily crystalline aluminum silicates. Hydrated oxides of iron and aluminum are also normally present in many soils.

The pH level of soil is another important factor in determining chemical decomposition rate. High humus soils tend to be acidic because many of the organic decomposition products are organic acid, such as acrylic, acrotonic, α-monohydroxy-stearic, benzoic, agroceric, oxalic, succinic, lignoceric,

Figure 12. AOMC Lysimeter Setup.

Figure 13. Tensiometer Tubing.

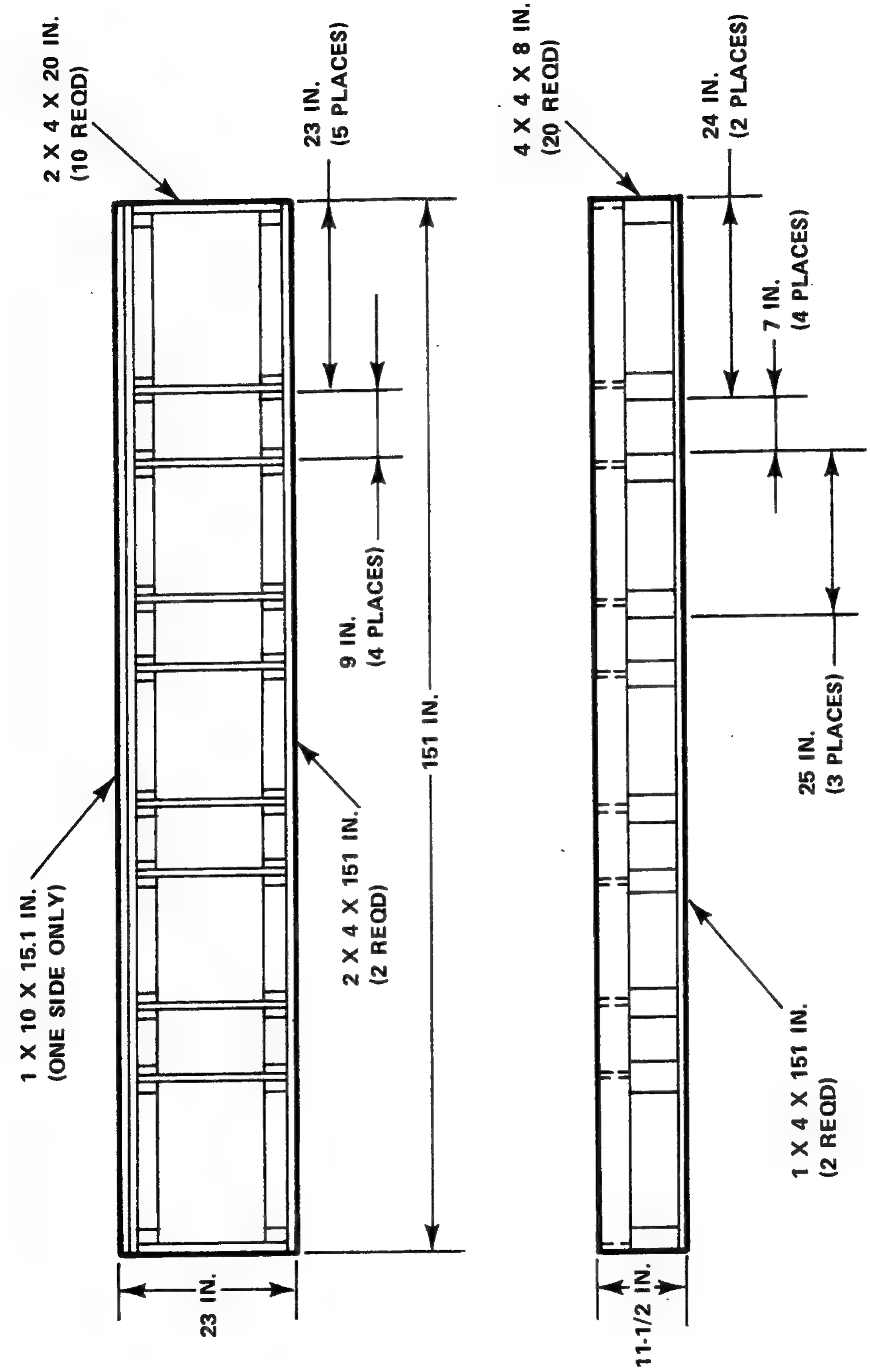


Figure 14. Lysimeter Stand.

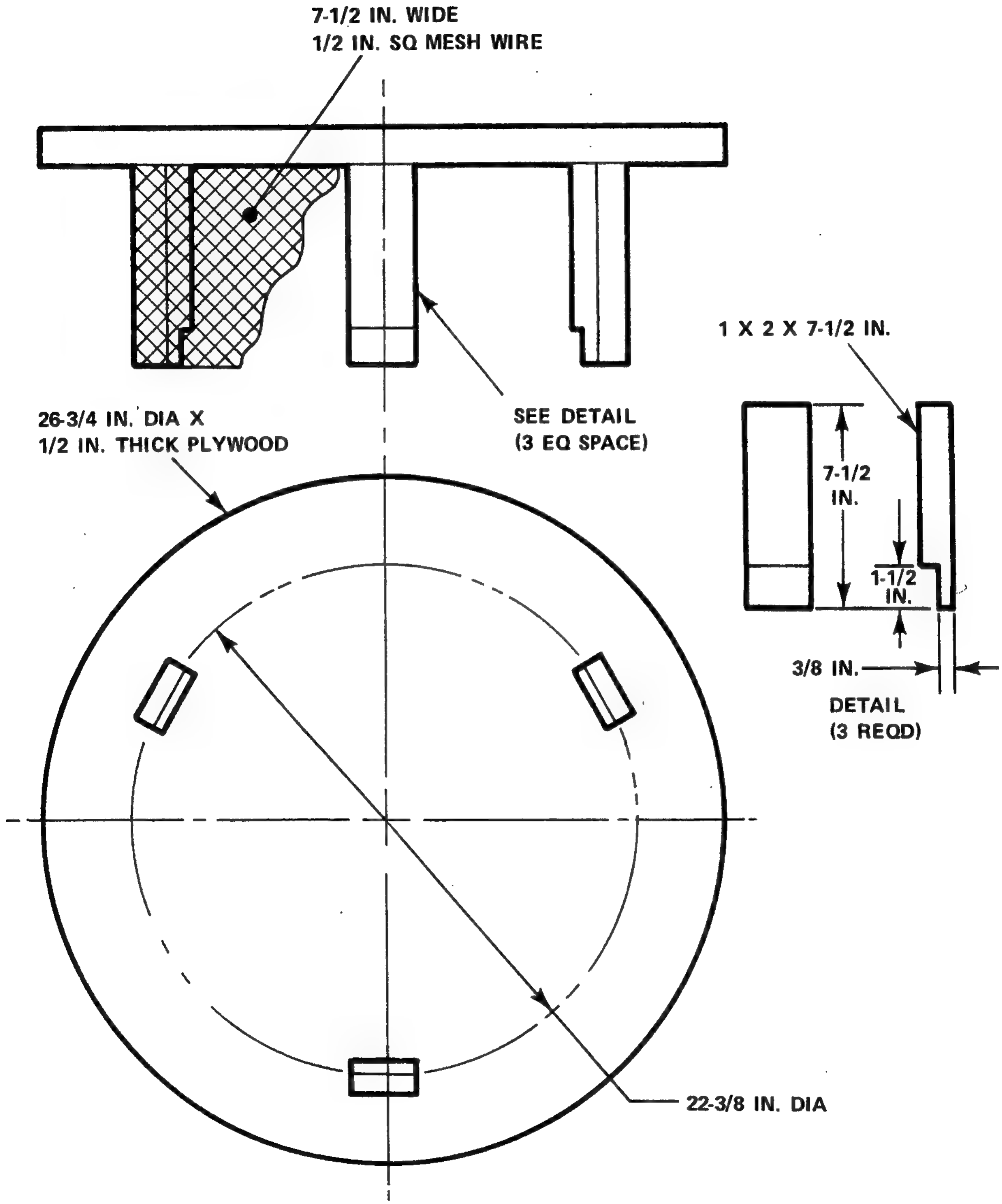


Figure 15. Lysimeter Cover.

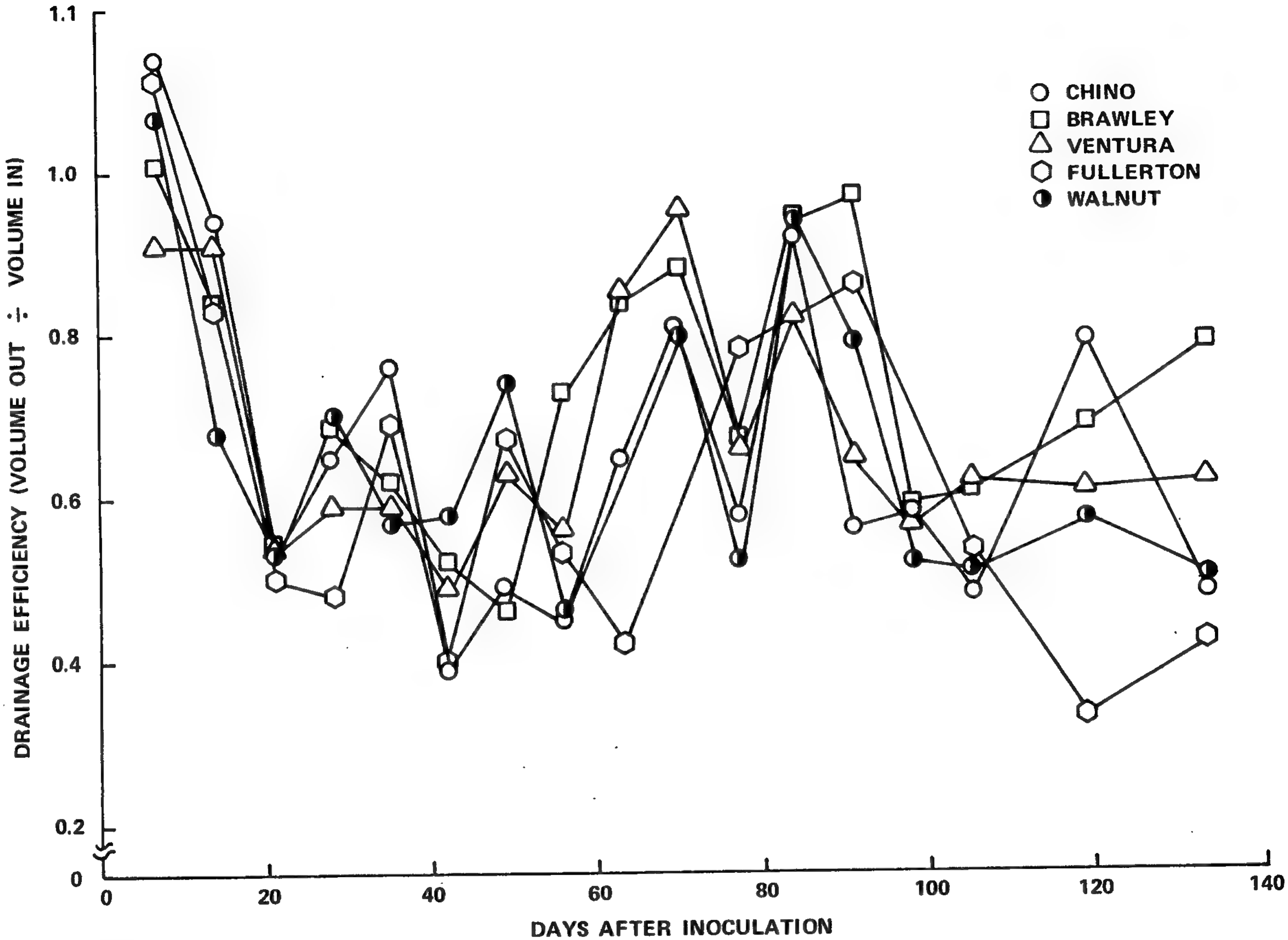


Figure 16. Drainage Efficiencies of Various Soils in Full-Scale Lysimeters.

humoceric, paraffinic, saccharic, di-hydroxy stearic, resin, metaoxytoluic, and para-hydroxybenzoic. Soils in dry areas often contain large amounts of soluble salts, including exchangeable sodium, and are referred to as salted soils. These soils may include either saline (i.e., sodium, potassium) or alkaline (i.e., calcium, magnesium) salts, or both, and tend to have a higher pH than soils in wet environments. The water available in high rainfall areas leaches the salts to neutralize the alkalinity. The pH of acid soils ranges from 3 to 7, but is rarely less than 4. The pH of alkaline soils ranges from 7.5 to 10, but normally does not exceed 8.5.

Quantitation of the chemical agent mobility in soils can be made by several methods, e.g., lysimeter experiments, in which one type of soil loaded into a tubular column has a charge of agent applied to the surface and periodic applications of water made to correspond to the rainfall level of the area of interest. As the applied water percolates through the soil column, samples are taken from time to time to follow the progress of the compounds through the soil. Distinction is made between the material carried in the water and material bound to the soil. The second method adds a known volume of a solution of known concentration (20 ppm) of agent in water at intervals (1 to 2 weeks) and follows the agent's progress through the soil.

Water samples are taken from the tensiometers as time passes and are analyzed for DIMP content. Table 6 is typical of the data gathered in this manner; one set of data is plotted in Figure 17. Soil samples are also taken at time intervals and analyzed. Table 7 and Figure 18 represent data from these samples. This is one type of data presentation used in the present study.

3.4 DATA HANDLING

The analytical data generated on the lysimeter program will be collected into a final report package which relates migration rate, time, irrigation rate, material balance, probable mechanisms of decomposition, and soil environment type. The data from the plant growth experiments will be subjected to regression analysis, which should result in an expression that defines the average yield values as a function of dose levels. An evaluation of the data reliability and suggestions for further study will be presented.

Table 6. DIMP Water Samples.

Type	Depth (in.)	Average From Previous Samples	DIMP (ppm) Days Since Inoculation 112	119	128	Average
Ventura	6	1.75	2.65	2.27	2.88	2.60
	18	0.31	--	1.18	0.97	1.08
	30	0.28	0.11	0.21	0.34	0.22
	42	0.36	0.58	0.78	1.08	0.82
	54	0.58	1.27	1.63	2.63	1.85
	60	2.65	3.23	3.26	3.26	3.25
Chino	6	1.50	4.82	3.84	7.98	5.55
	18	0.79	2.26	3.80	7.18	4.42
	30	0.66	1.91	2.86	--	2.39
	42	0.20	2.14	2.60	--	2.37
	54	0.14	0.89	1.37	2.86	1.71
	60	0.28	1.30	1.27	2.74	1.77
Fullerton	6	5.79	4.36	3.64	5.69	4.55
	18	2.33	2.75	2.50	4.05	3.10
	30	0.50	1.25	1.55	2.82	1.87
	42	1.43	0.71	0.86	1.55	1.04
	54	0.20	0.51	0.51	1.16	0.73
	60	0.61	0.73	0.60	1.15	0.83
Walnut	6	1.83	--	--	5.47	5.47
	18	2.27	1.49	1.96	5.09	2.85
	30	0.94	1.81	2.66	4.00	2.83
	42	0.94	1.41	2.10	4.53	2.68
	54	0.24	0.25	1.26	2.25	1.25
	60	0.19	1.06	1.40	2.48	1.65
Brawley	6	3.18	3.28	3.55	8.87	5.23
	18	1.27	--	3.45	7.69	5.57
	30	0.50	1.32	1.93	5.95	3.07
	42	0.41	1.13	2.21	5.76	3.03
	54	0.83	0.66	0.74	2.21	1.20
	60	0.42	1.41	1.59	4.52	2.51

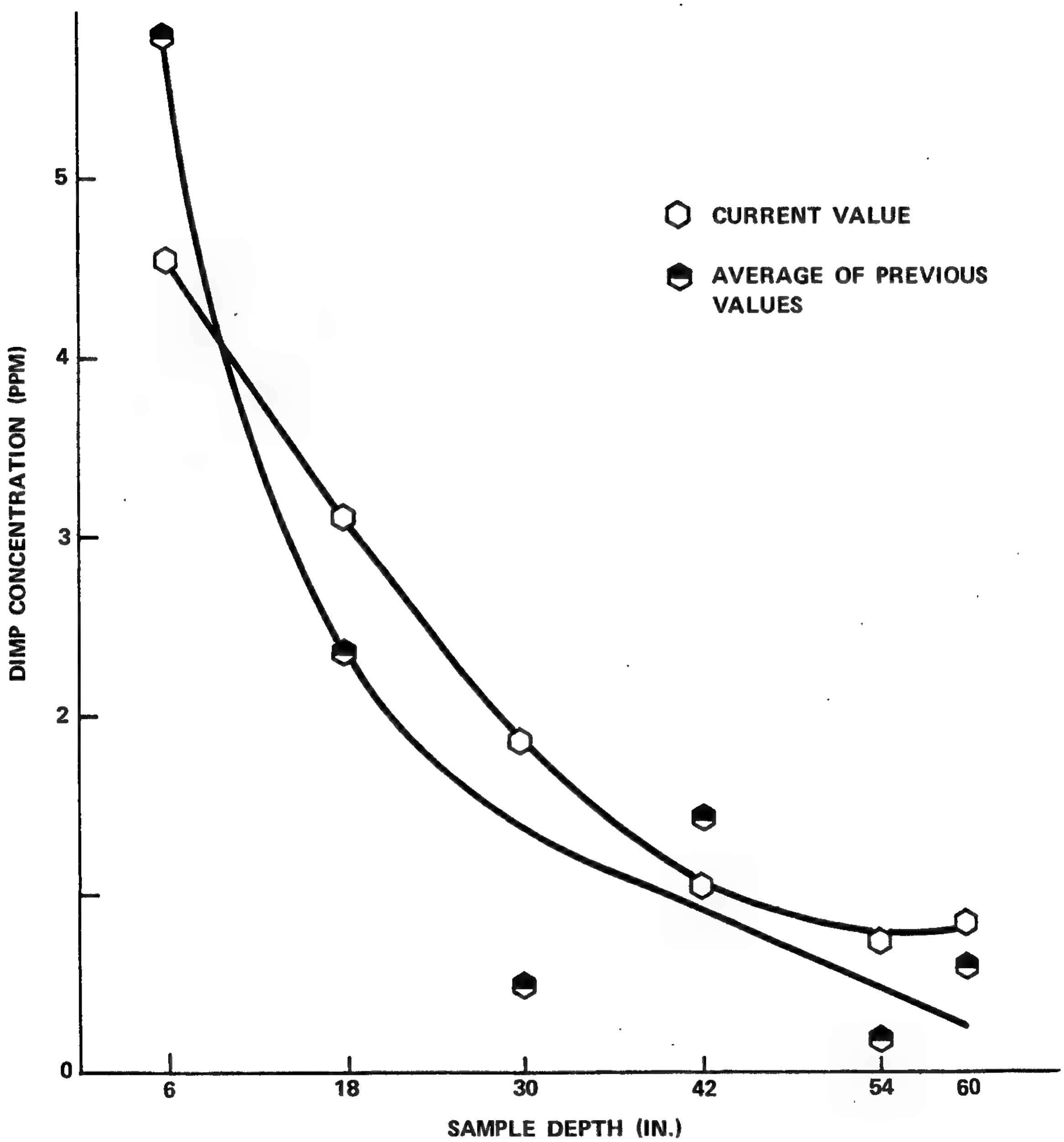


Figure 17. DIMP Content of Tensiometer Water Samples (Fullerton).

Table 7. DIMP Content of Soil Samples (ppm) -- 133 Days.

Depth (in.)	Ventura	Chino	Fullerton	Walnut	Brawley
0 (surface)	15.77	20.66	11.61	9.49	19.85
0 - 6	3.07	10.10	5.70	10.54*	5.71
6 - 12	3.47	7.34	6.45	4.75	3.10*
12 - 18	1.46	4.81	3.88	5.11	2.71*
18 - 24	1.07	4.34	3.51	4.07	2.53*
24 - 30	1.37	4.21	3.93	4.61	2.32*
30 - 36	1.92	4.96	3.14	4.67	3.92
36 - 42	2.20	4.10	4.36	3.82	3.98
42 - 48	2.58	3.17	3.08	4.83	3.58
48 - 54	2.26	3.57	3.03	3.00	3.27
54 - 60	2.97	2.80	2.19	2.09	3.88

*Estimated

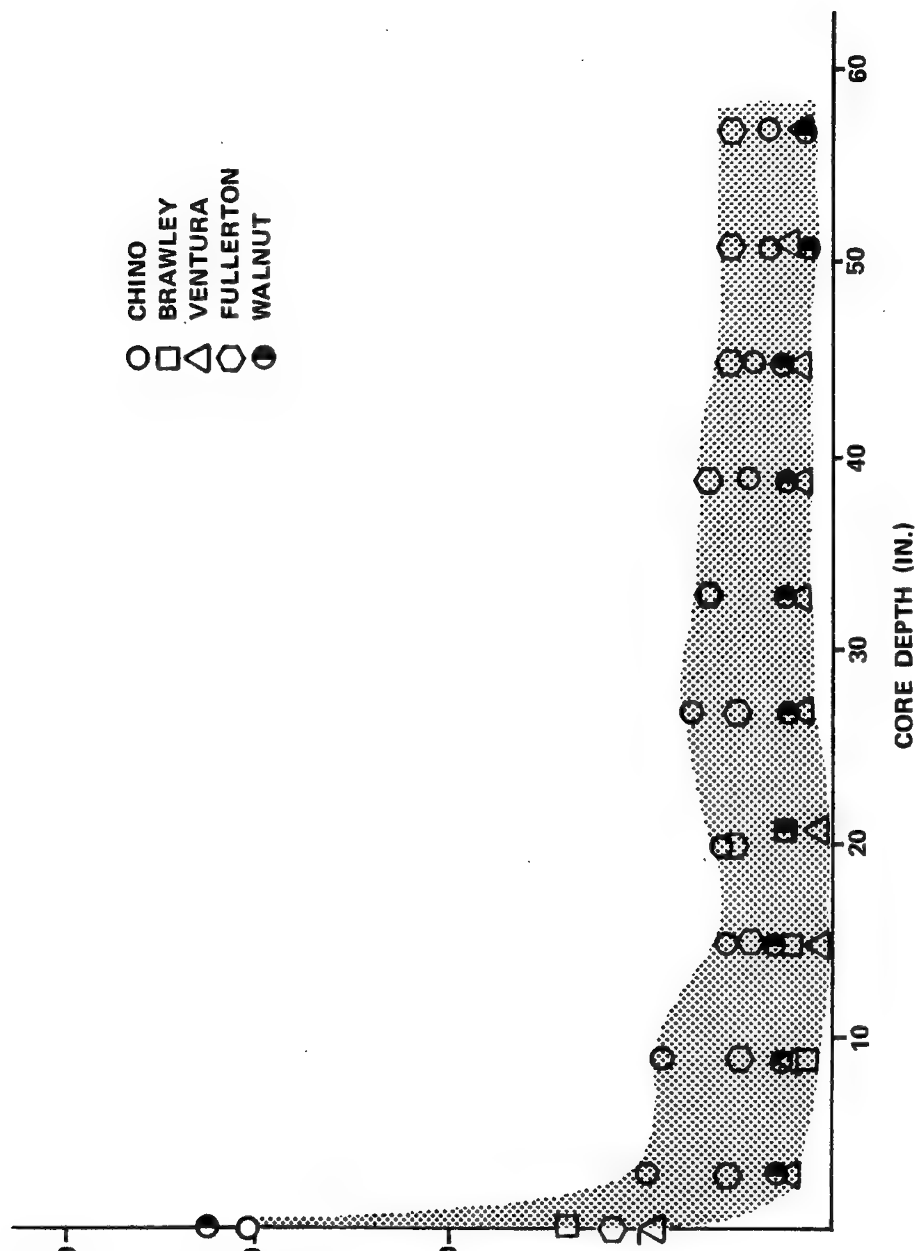


Figure 18. Analyses of Lysimeter Core Samples for DIMP.

Section 4

FACILITIES

4.1 CHEMICAL STUDIES GROUP

The capability of a company to perform research and development programs is expressed in terms of its facilities, its personnel, and its record of successful performance in a field of interest. For more than 19 years, members of AOMC's Chemical Studies Group have been engaged in programs such as the following:

- Aerosol Research
- Environmental Pollution
- Reaction Kinetics
- Quantitative Analysis
- Qualitative Analysis
- Hydroponics - Horticultural Testing
- Explosive Analysis
- Health Physics

Approximately 700 acres of open ranch land are accessible within the confines of the AOMC Chino Hills laboratory area. Typical of the protected areas available for use as lysimeter pads is that shown in Figure 19, a 10- by 25-ft concrete pad. Structures are also available for providing support for an aluminum roof.

The basic laboratory facility was designed around requirements for conducting aerosol research with highly toxic compounds. Extensive effort was made to provide a laboratory that would encompass all the possible safety provisions for dealing with hazardous chemicals with respect to toxicity as well as handling of explosives. The laboratory was expanded to include related or supporting analytical capabilities in the ordnance field resulting in a highly versatile facility.

Figure 19. A Proposed Lysimeter Pad Area.

Invaluable experience has been gained in conducting and assessing agent dis-emination generation and compatibility tests. This experience includes handling such agents as CS, CS1, CS2, VX, GB, GD, BZ, EA-3443, EA-3580, EA-3834, EA-1356, and EA-3317. All standard military explosives and propellants, as well as exotic high temperature and low pressure explosives, have been studied.

4.1.1 Aerosol Research Laboratory

AOMC is one of only a few privately owned companies capable of investigating aerosols of lethal chemical compounds and analyzing or evaluating chemical detection systems. Its laboratory is one of the most complete facilities available in industry, meeting safety requirements and military specifications associated with testing toxic chemicals (Figure 20). The building is air-conditioned, and each room is maintained at a different relative pressure so that air tends to flow toward the area of most probable toxicity. The facility includes an aerosol test chamber, chemical and instrumental laboratories, first-aid station, work shop, personnel decontamination facilities, and administrative offices.

The aerosol chamber, a 21-ft diameter by 20-ft high steel vessel, was designed to perform aerosol tests with toxic materials. Several dissemination methods are used, including explosive, thermal, pneumatic, and pyrotechnic. Aerosols generated in the chamber are sampled through ports in sealed glove boxes and observed through windows for photographic and photometric monitoring. Particulate and droplet fallout is measured with trays and slides placed on the floor of the chamber. The aerosol samples are chemically and physically analyzed in the toxic laboratory adjacent to the chamber room or passed through air locks to other laboratories as applicable for analysis. A set of six lysimeters requires 30 sq ft of floor area. The air-conditioned chamber room has adequate floor space for operating with 24 lysimeters of the type described in this proposal without interfering with the working area.

4.1.2 Analytical Laboratory

The analytical Laboratory is equipped for rapid and accurate analysis of collected aerosol samples for chemical composition and concentration as well as particle-size distribution of particulate matter (Figures 21 and 22). Operations performed include techniques for gas chromatography; thin-layer chromatography; infrared, ultraviolet, and visible spectrophotometry; polarography; calorimetry; photomicrography; and gravimetric and volumetric

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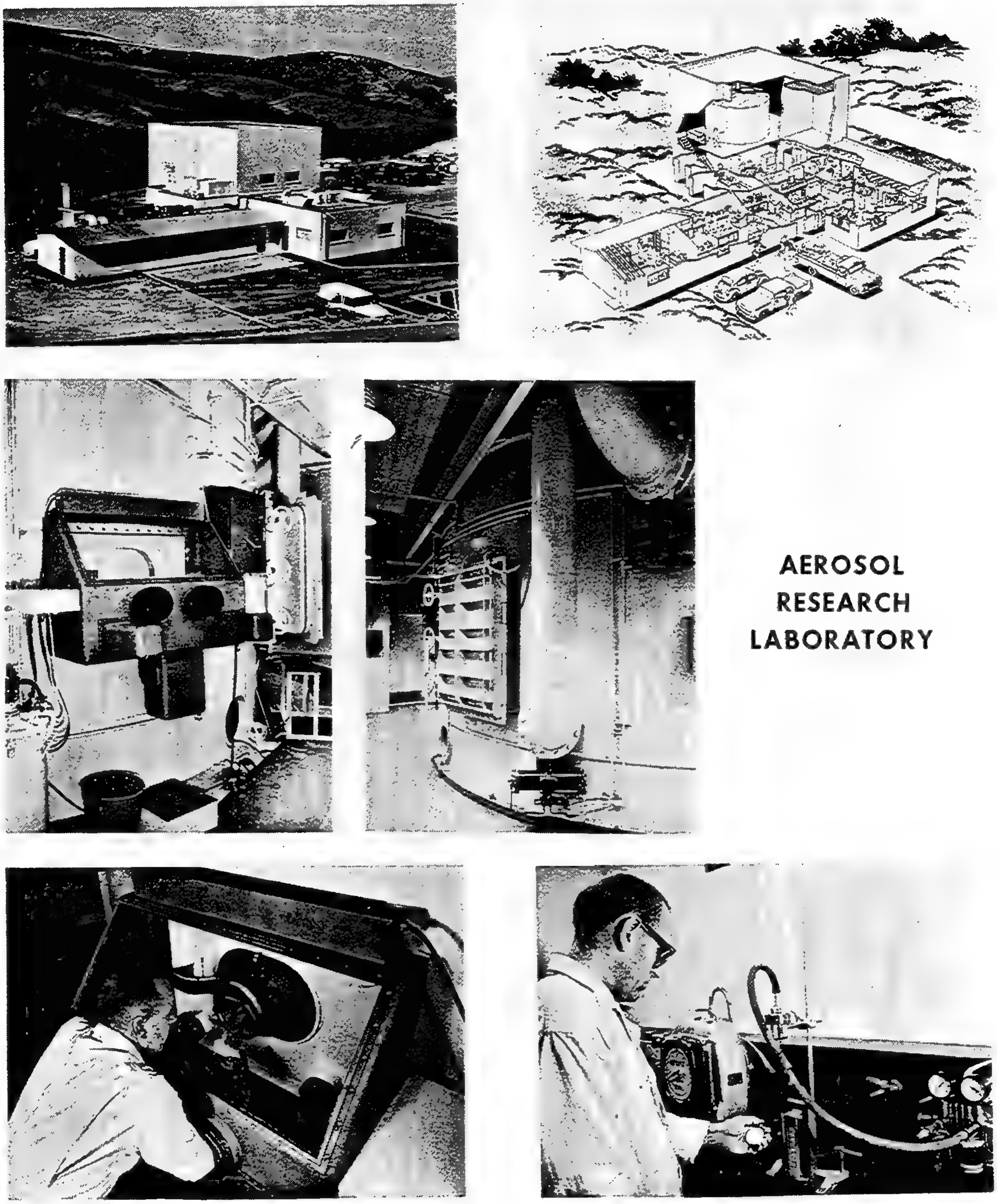
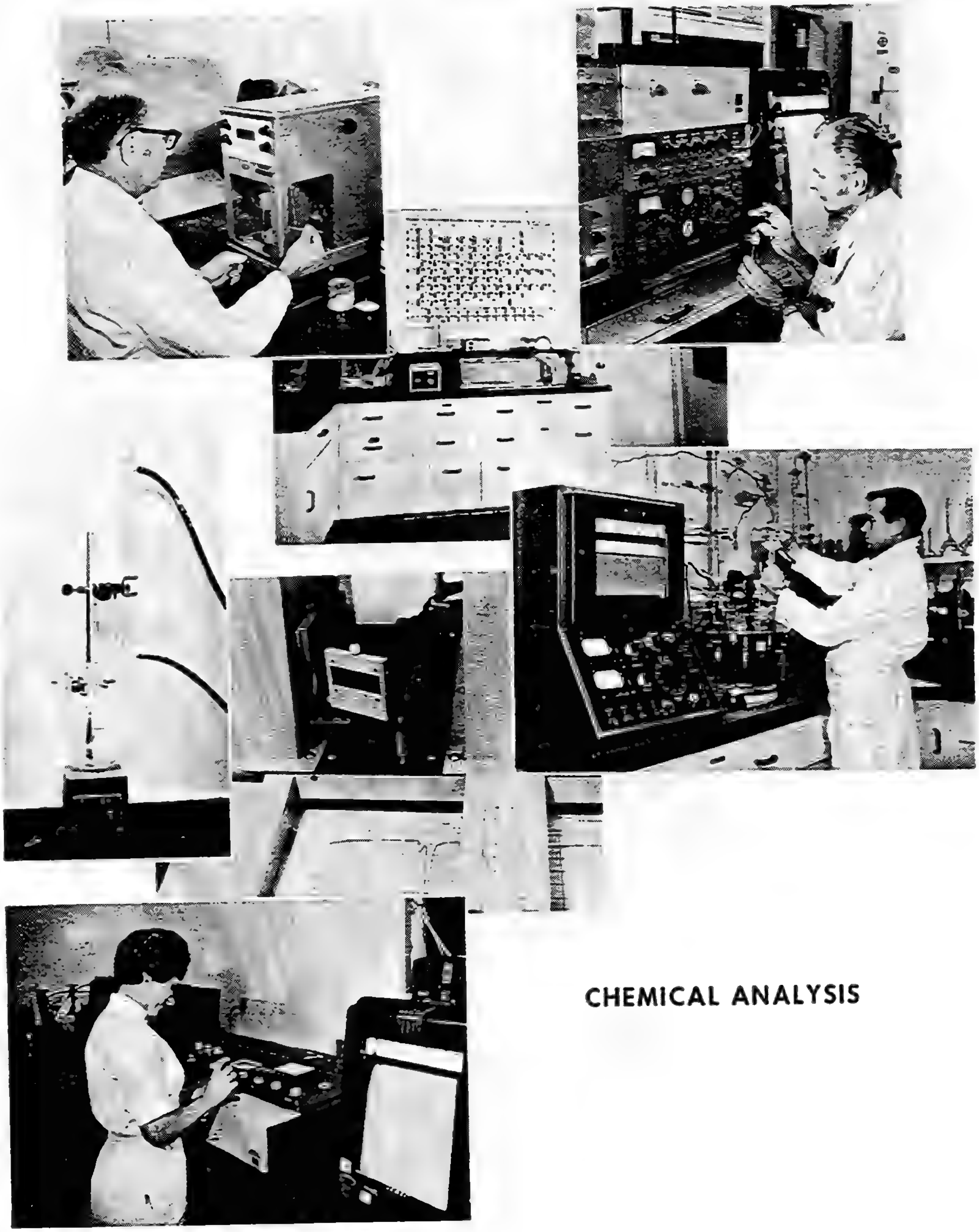
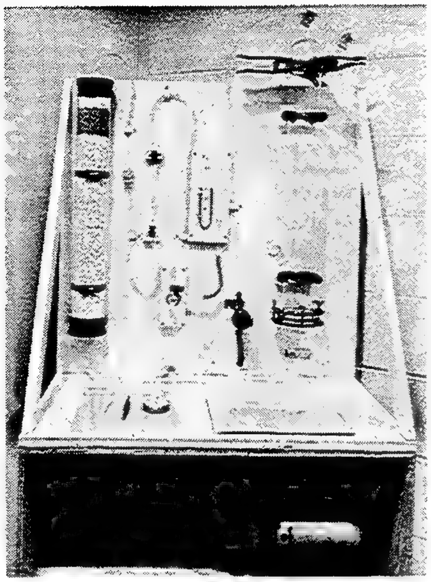


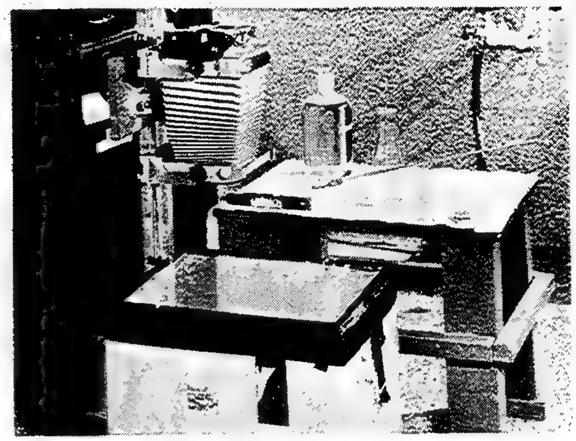
Figure 20. Aerosol Research Laboratory.

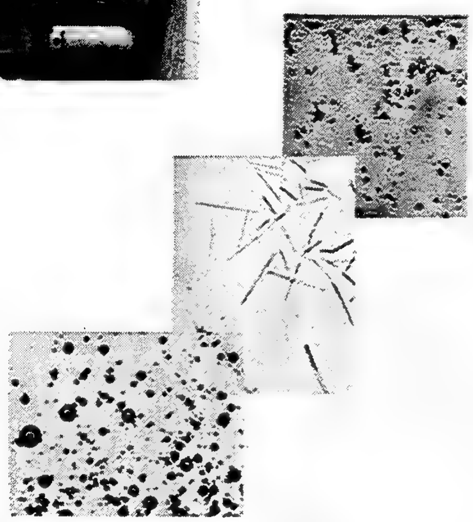


CHEMICAL ANALYSIS

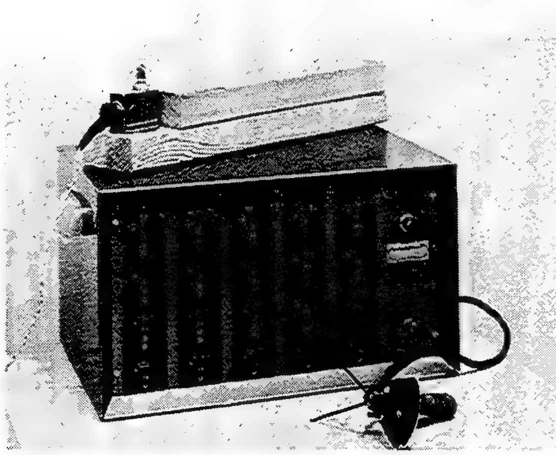
Figure 21. Analytical Laboratory: Chemical Analysis.







PARTICLE PROPERTIES
ANALYSIS



22. Analytical Laboratory: Particle Properties Analys

quantitative analysis. Qualitative wet chemical analyses are also conducted. Facilities for physical analysis, small-scale aerosolization experiments, and organic and inorganic synthesis are available.

The laboratory floor space is 3500 sq ft, of which 2500 ft can normally be devoted to this program.

Examples of programs requiring the extensive services of the analytical laboratory are as follows:

a. Analysis of toxic aerosols for both chemical and physical parameters.

b. Identification and analysis of chemical agent decomposition products in vegetation and soil.

c. Use of radioactive tracers in plant metabolism studies.

d. Reaction kinetics for toxic chemicals produced in binary reactor systems.

e. Property measurements of particulates, such as size distributions, agglomeration, surface energy, density, and flowability.

f. Qualitative analysis of trace constituents that use chemical spot tests, GLC, IR, UV, and TLC techniques.

g. Explosive analyses by DTA, vacuum stability, drop test sensitivity, and chemical composition.

h. Storage stability of materials for compatibility under accelerated or special storage conditions.

i. Air pollution studies for emissions from incineration of explosive and related materials.

j. Field studies of chemical stability in real environments.

4.1.3 Horticultural Research Capabilities

AOMC has been active in studies of detection and effects of trace quantities of chemicals on plants. Chemical contaminants in water or atmosphere have been successfully monitored for absorption, deposition, and transmission to various parts of plants. Of special concern has been the analysis of decomposition products to identify contaminants absorbed by plants (Figure 23).

Controlled conditions are maintained for hydroponically cultured plants in greenhouses. Nutrient solutions are monitored and additives are introduced, the signatures of which are subsequently analyzed in the vegetation. Included in techniques used are radioactive tracers for rapid monitoring of translocation of investigated materials. Qualitative and quantitative chemical and instrumental procedures are applied to extracts of plant materials, such as gas-liquid chromatography, thin layer chromatography, and spectrophotometric analysis.

Other methods of plant research used at AOMC include studies under field conditions with outdoor test plots. Also, samples are collected at field sites under actual circumstances of contamination and analyzed in the laboratory.

Plant types investigated have included grain forage and vegetable crops, deciduous and coniferous trees, and fruits.

4.1.4 Reaction Kinetics

AOMC has conducted many tests with specially designed reactors to optimize parameters for toxic chemical producing reactions (Figure 24). Small-scale reactors were fabricated and equipped with propellant injection systems for rapid blending of reactants. The reactors were monitored for temperature and pressure and equipped with automatically timed sampling and quenching devices. Data obtained were used to establish design for large-scale reactors. Extensive tests were conducted on large reactors to verify maximum yields based on concentration of reactants, temperature, agitation, and physical characteristics of the hardware.

Techniques have been successfully developed to handle and assess both liquid and solid reactant systems. Chemical stability of reaction products has been studied at resultant temperatures and pressures developed in reactors.

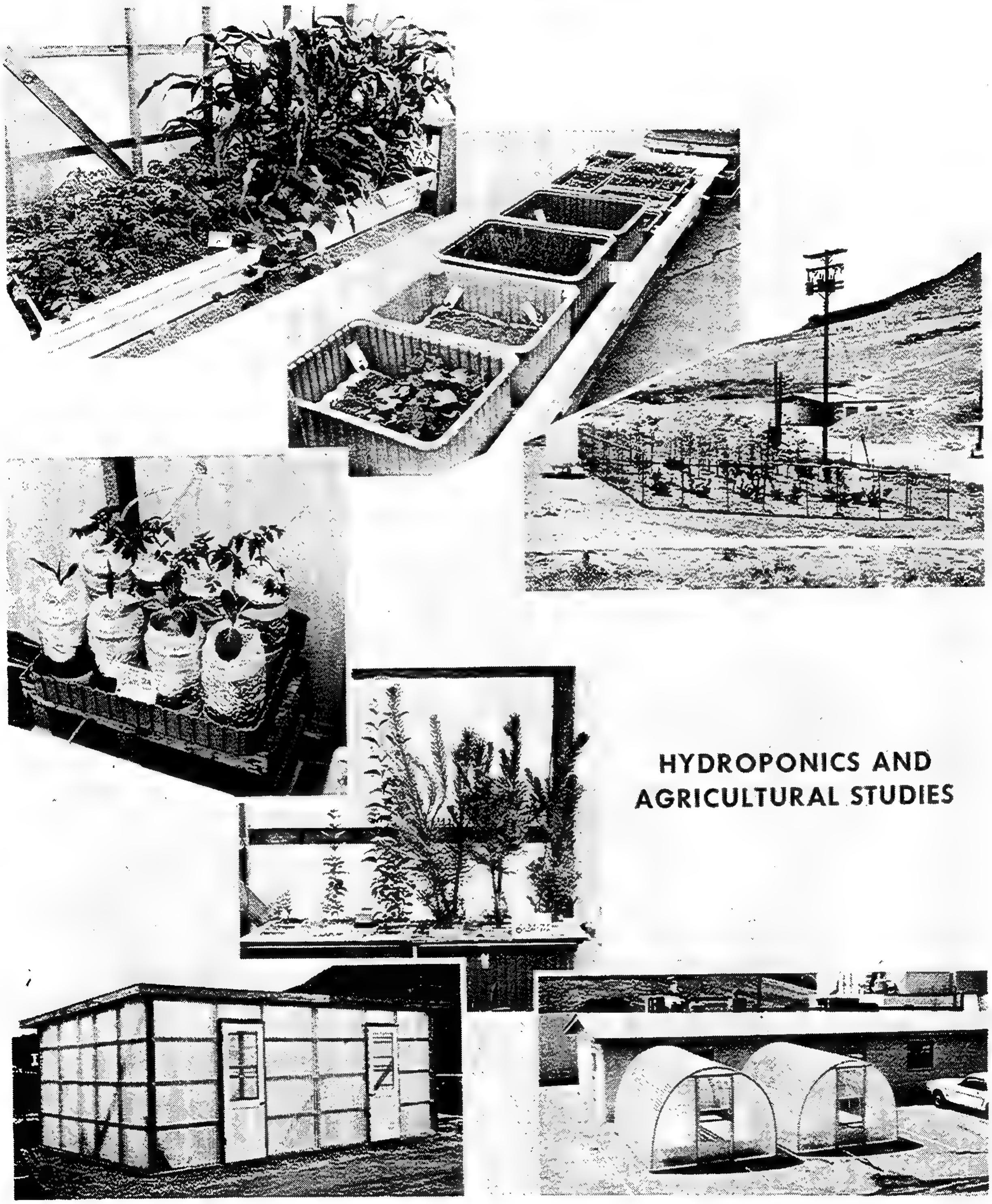


Figure 23. Hydroponics and Agricultural Studies.

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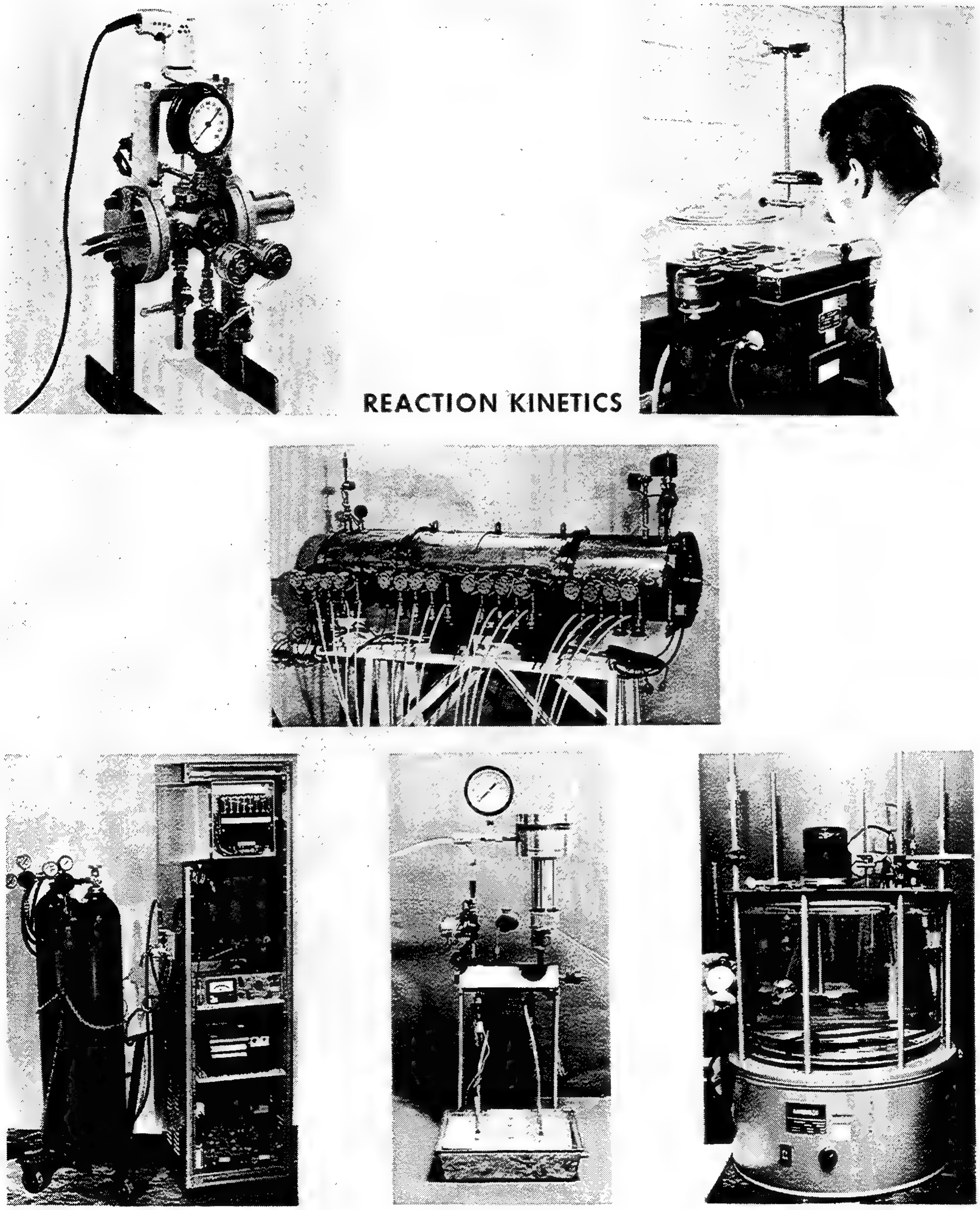

Figure 24. Reaction Kinetics.

4.1.5 Environmental Pollution

AOMC has developed acceptable methods for disposal of surplus hazardous materials, such as explosives, propellants, and affiliated materials (Figure 25). Specially designed incinerators with afterburner equipment have been investigated. Regulations and procedures of reference used are those of the Los Angeles County Air Pollution Control District.

Sampling methods, such as impingers and grab and gas tubes are used to analyze stack effluents. Monitored constituents include particulate, water vapor, CO_2, CO, O_2, N_2, oxides of sulfur, oxides of nitrogen, organic acids, ammonia, and aldehydes. Ringleman measurements have been made on smoke density.

Waste materials generated in the laboratory and in AOMC's production facilities are analyzed. Waste solutions from cleaning up after tests with toxic chemicals are analyzed for possible toxic residues and other constituents before transfer to plastic-lined evaporation ponds. Washings from manufacturing facilities that use explosives are tested for possible residues that might contaminate the environment. Included in the environmental safety program is a closely controlled effort for prevention of radioactivity contamination during manufacture and test of hardware containing depleted uramium.

4.1.6 Health Physics

In conducting manufacturing and research programs which required stringent standards and control of working conditions, AOMC has developed capabilities and experience in health physics (Figure 26).

Machining and testing hardware consisting of depleted uranium components requires rigid procedures to monitor and control residual radioactive contaminants. Shop areas, machinery, and personnel are checked routinely during manufacturing operations. Measurements are made to meet shipping requirements. Hardware testing is monitored for radioactive fragments and radioactive aerosols generated from burning uranium. Control measurement of heavy metals is conducted for certain aerosol or dust-producing operations, where applicable.

This effort is coupled with capabilities of monitoring toxic organic chemical aerosols studied in AOMC's Aerosol Laboratory.

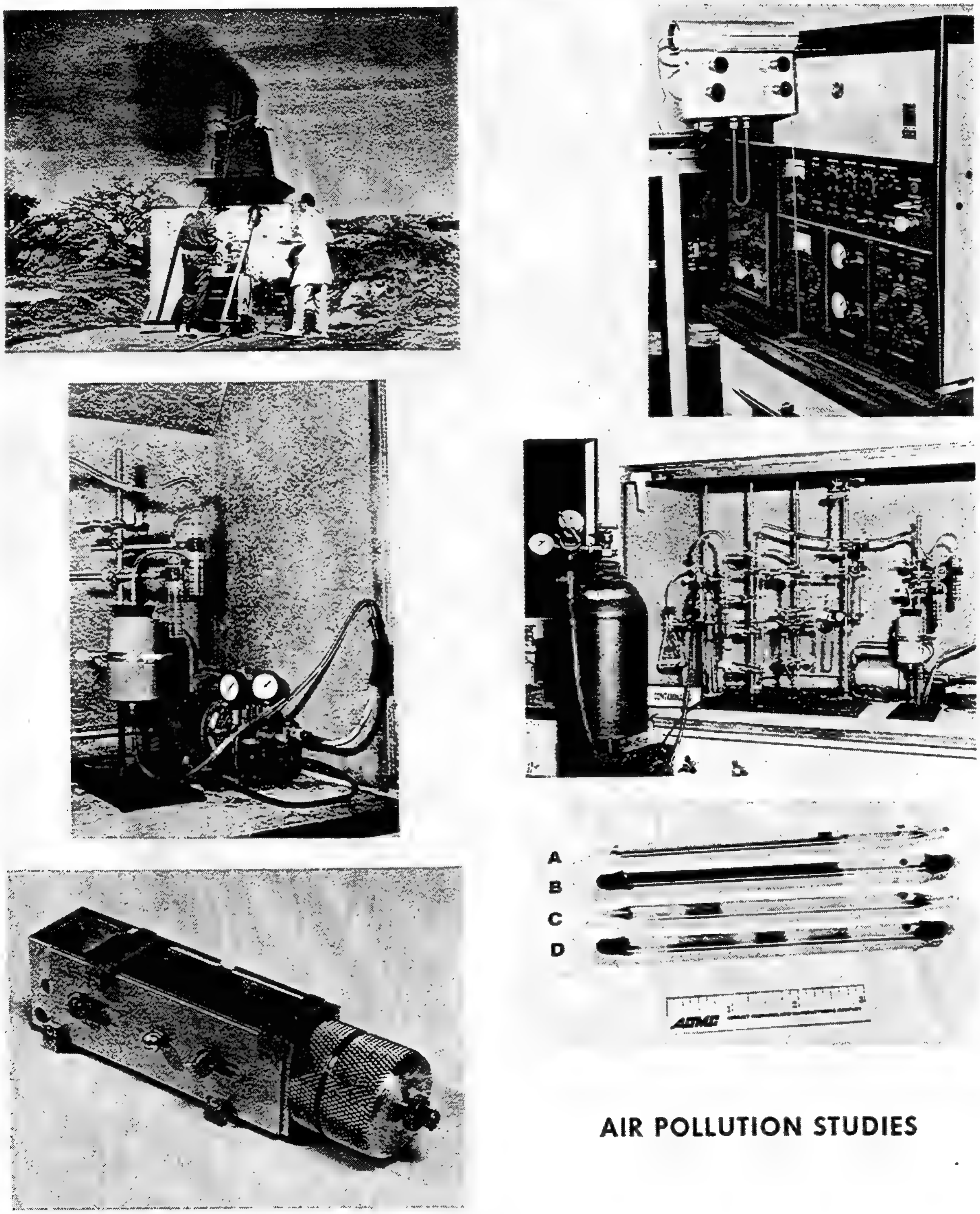

Figure 25. Air Pollution Studies.

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HEALTH PHYSICS

Figure 26. Health Physics.

4.2 ENGINEERING

In the Downey engineering laboratory, project personnel have access to extensive library, computer, and documentation facilities. The laboratories, which include test and fabrication services, provide support on advanced research and development, aerodynamic studies, electronics development, and the integration of complex systems. These laboratories are equipped to provide an engineering concept from feasibility and development testing through qualification of the finished product.

4.2.1 Library

The Downey engineering facility maintains a modern technical library supervised by a professional librarian. This collection of technical reports, abstracts, indexes, books, and journals (current and retrospective), ensures immediate access to the many fields of knowledge required for problem solution in widely varied scientific disciplines.

The Downey library contains a keyword index, abstract files, and in-depth collections of technical reports and journals. The documents have been obtained from the library services of Government agencies, such as DDC, NASA, and AEC. Aerojet's Azusa and Sacramento libraries maintain valuable additional material such as the Corporate Technical Information Center, which provides abstract services to all Aerojet facilities. Other excellent and frequently used technical libraries are those at the California Institute of Technology, the University of California at Los Angeles, the University of Southern California, and the Pacific Aerospace Institute.

4.2.2 Computer Facilities

AOMC's modern computer center is available to support the program. It has computer programs, experienced programmers who can assist in developing mathematical models and writing computer programs, and third-generation, high-speed computers to process the data.

AOMC's computer capabilities provide all necessary services in the automatic processing field and associated disciplines. Complete services are offered, ranging from complex engineering problem solution to business systems design and computer programming. An array of modern third-generation digital computers supports internal corporate and external Government and industrial requirements.

Of particular interest to the proposed program is the computing equipment available at the Downey facility. An IBM 1130 digital computer with disk-pack, card read-punch, and printer is used almost exclusively for scientific computing. Many AOMC engineers are competent programmers and have the 1130 available to them on a hands-on basis, in addition to standard remote-batch job entry. This equipment minimizes job turnaround time. AOMC also maintains a programmer-analyst staff to support Government contracts.

AOMC's Engineering Terminal System (ETS), which is linked with the IBM 360/75 and 65, enables the engineer to rapidly solve smaller problems not warranting the use of larger computing equipment.

4. 2. 3 Documentation

The documentation facilities at Downey include the photographic laboratory and publication services.

4. 2. 3. 1 Photographic Laboratory

The latest optical and photographic equipment, operated by experienced technicians, is available for recording data and documenting tests, including photo test coverage of airborne weapons under operating conditions.

4. 2. 3. 2 Publications

Engineering writers originate and edit text for various forms of technical documents, reports, specifications, manuals, proposals, and brochures. The editor assigned to each program supervises preparation of art work, photography, and reproduction.

Technical artists prepare illustrations and charts for all publications, with techniques ranging from line art through full-tone art.

Printing for the Downey facility is accomplished by offset lithography. Documents are collated and assembled into final form in the print-shop. In addition, the printshop maintains a large reproduction department for making prints, autopositives, sepias, and electrostatic copies.

Section 5

RELATED EXPERIENCE

Contract No. /Customer	Description
Four classified contracts	Programs involved the investigations for qualitative and quantitative analysis of toxic chemicals and their products in soil and vegetation. Techniques included greenhouse hydroponics and field vegetation experiments supported by trace chemical analytical procedures.
Three classified contracts	Programs dealt with the analysis and evaluation of chemical detection systems for toxic compounds.
DAAA-15-67-C-0643 AMC	Immuno-Chemical Detection Study. Development of new chemical reaction for detecting CW agents.
Nyb 62211 Navy	Detection of Chemical Contamination in Water Reservoirs. Evaluation of a new technique for detection of CW agents in water supplies.
DA-18-064-AMC-137A AMC	Biological Warfare Detection. Collection and concentration of aerosols; chemical, biological and physical methods of detection and identification of pathogenic microorganisms.
F08635-68-C-0073 AF	Improved Dissemination Study. A study of explosive dissemination techniques for chemical agents CS and BZ.
DAAA15-69-C-0632 AMC	New Agent Dissemination. Investigation of chemical and physical characteristics of new candidate agents in explosive dissemination processes.
DAAA-15-70-C-0260 AMC	Optimization of CS2 for Terrain Denial Modification of surface properties of agent CS2 to increase its aerosolizability and effectiveness.
DAAA-15-69-C-0738 AMC	Polymer/Difluor Compatibility Study. Provide detailed data on the compatibility of plastic materials with methylphosphonic difluoride with respect to effects on purity and reaction characteristics.
DAMD17-75-C-5069	Determination of Decontamination Criteria, DIMP and DCPD. Conduct soil/lysimeter experiments to determine mobility of organic chemicals in soil profiles. Determine uptake, distribution, and concentration of contaminant organic chemicals in growing plants.

Section 6

PROGRAM MANAGEMENT

AOMC recognizes that informal and efficient management must accompany technical excellence to ensure program success. This section discusses the planning, staffing, and control elements to be used in the proposed study.

The proposed program will be assigned to the Technical Services Section under the direction of T.L. Dressel, who reports to W.L. Haubein, Vice President of Engineering. Figure 27 shows the relationship of the group to the Engineering organization.

The proposed program will be under the direction of P.A. O'Donovan, Chemical Specialist. Mr. R.L. MacLean, also a chemical specialist, will be a staff consultant to Mr. O'Donovan. Consultants in the area of soil sciences are currently under contract to AOMC and are being utilized on similar work at present. They will be available on an intermittent basis as required by this program. Resumes of Dr. J.P. Martin and H.D. Chapman from the University of California at Riverside are included.

Mr. MacLean has experience in establishing a hydroponics study program for determining CW agent absorption and transmation in vegetation. He has developed significant modifications to standard gas-chromatographic techniques of analysis for application to CW agents and related compounds. He has many years of experience in large scale column chromatography and instrumental and microanalysis.

Mr. O'Donovan has been in charge of the Toxic Chemical Laboratory for many years, directing all chemical analysis activities, scheduling, and supervising laboratory personnel. He has been responsible for the performance of all CW agent analyses. He has also directed and performed explosive and CW experiments, including kinetic reaction studies, analytical procedure development, aerosol sampling, radioactive tracer techniques, and vegetation/soil distribution studies.

The proposed effort will also require a test engineer, a laboratory technician, and an associate chemist to work full time under the direction of Mr. O'Donovan. Additional AOMC chemistry specialists (such as Dr. Nishibayashi) may be used in an advisory capacity, as required.

Under the leadership of Mr. O'Donovan, the proposed project team will provide a high probability of achieving the program objectives.

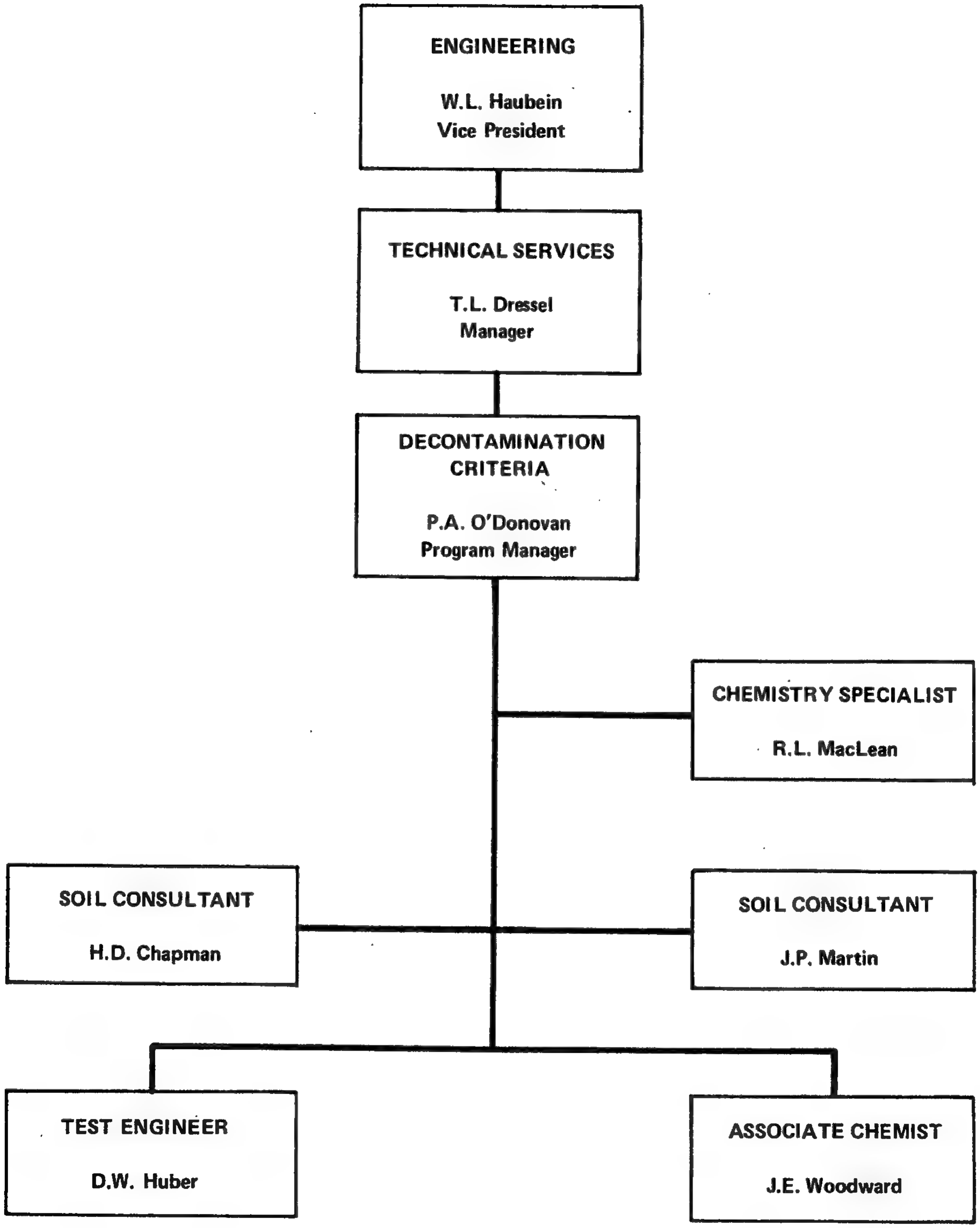

Figure 27. Proposed Program Organization.

P. A. O'DONOVAN
Technical Director
Chemical Laboratories

EDUCATION

B.S., Chemistry, University of Portland, 1950.
M.S., Physical Chemistry, University of Portland, 1951.
Graduate Studies, University of Florida, 1951 to 1952.
Graduate Courses in Infrared Spectrophotometry, Gas Chromatography, and Instrumental Analysis, University of California, 1964 to 1967.

WORK HISTORY

1959 to date: AOMC. Technical Director of the Munitions Evaluation Laboratory.

1954 to 1959: Nutrilite Products, Inc. Research Chemist.

1953 to 1954: American Potash and Chemical Company. Research Chemist.

1951 to 1952: University of Florida. Research Assistant.

1950 to 1951: University of Portland. Teaching Fellow.

EXPERIENCE

Serves as technical director of the Munitions Evaluation Laboratory and associated analytical chemistry laboratories. Directs all chemical analysis activities, schedules and supervises laboratory personnel, and provides analytical chemistry services for AOMC. Responsible for the safe operation of chemical agent tests.

Performed binary (lethal) CW agent generation tests and associated analytical procedures on Bigeye and AOMC IR&D projects, including VX, GB, and GD agents.

Performed studies on mobility and stability of various CW related compounds in soil and water.

Performed hydroponic plant growth experiments with associated chemical uptake and retention investigations related to CW materials.

Performed radiation health physics duties at Downey and Chino AOMC plants.

Set up gas-liquid chromatograph, spectrophotometric and wet chemical procedures for the analysis of binary agent products and evaluation of kinetic data on these reactions.

Accomplished synthesis and isolation of physiologically active substances from plant materials. Also performed formulation and stability studies on various pharmaceutical products.

Performed studies, prepared design tests, and performed chemical analyses on Contract AF08(636)-4496, Selected Chemical Munition, for Eglin Air Force Base.

Performed theoretical and experimental studies on the breakup of solid and liquid agents in explosive dissemination.

Conducted electrochemical and spectrophotometric analyses of organic and inorganic materials, including toxic CW compounds.

Performed ultrahigh-speed photographic investigations of explosive phenomena, and conducted a fundamental study of detonation mechanisms in solid and liquid explosives.

Studied sensitivity and stability of explosive compounds.

Conducted general analytical and quality control programs.

Conducted basic studies on the physical chemistry of fluorocarbons.

Taught general chemistry and qualitative analysis.

Accomplished synthesis and electrochemical characterization of substituted propylpyridinium salts.

R.L. MAC LEAN
Chemistry Specialist

EDUCATION

B.A., Chemistry, Whittier College, 1949.
M.S., Organic Chemistry, University of California, Berkeley, 1951.

WORK HISTORY

1961 to date: AOMC. Chemistry Specialist.

1951 to 1961: Nutrilite Products, Inc. Manager of Product Development.

EXPERIENCE

Investigated CW agent and byproduct absorption in vegetations cultured in hydroponics environments, using chemical, and radioactive tracer techniques. Studied soil retention of related compounds and techniques for detection and analysis.

Program Manager for pelletized CS2 study.

Program Manager for the Improved Dissemination Techniques program, a major effort in explosive dissemination oc CS and BZ.

Program Manager for the Prototype Munition Dissemination System effort dealing with CS, and other incapacitating agents.

Conducted parametric studies on the dissemination of solids and liquids in aerosol test chambers. A large portion of the work dealt with aerosols of toxic materials.

Responsible for planning and supervising the first toxic agent dissemination tests conducted in AOMC's Munitions Evaluation Laboratory.

Responsible for all toxic testing of the first Bigeye binary VX reactors at AOMC.

Program Manager for the Investigation of Coalescence of Solid/Liquid Systems program.

Conducted experimental programs for coalescence of droplets for the U.S. Army Signal Corps.

Conducted parametric investigation for dissemination of solids, powders, liquids, and slurries.

Studied pyrotechnic dissemination of intimate mixtures of agents.

Studied wind-tunnel atomization of liquid agents from binary reactions.

Conducted studies in the assessment of particles in aerosols; developed a photoextinctinction particle-size assessment instrument.

Investigated and correlated particle sizing methods (Whitby centrifuge, micromerograph, millipore filters, photoextinction, and sieving).

Conducted theoretical and experimental studies of flashing in explosive dissemination of liquids.

Conducted high-speed photographic fundamental studies of explosive shock and solids and liquids related to dissemination and fracture.

Has experience in product development of cosmetic and pharmaceutical formulations. Conducted compatibility and stability investigations on cosmetics products containing FDA-approved dyes and naturally occurring coloring agents.

Investigated the development of processes for extracting and concentrating physiologically active substances from plant materials. Investigated spectrophotometric techniques for intensifying and monitoring factors in processed concentrates. Planned and supervised installation of a pilot plant for food and drug processing development. Conducted analytical chemistry investigations of vitamins and minerals.

J. E. WOODWARD
Associate Chemist

EDUCATION

B.S., Biochemistry, University of California, Riverside, June 1975.

WORK HISTORY

1975 to date: AOMC. Associate Chemist.

1974 to 1975: University of California, Riverside. Laboratory Assistant.

EXPERIENCE

Conducted gas-liquid chromatographic, spectrophotometric and wet chemical procedures on plant tissue samples.

Prepared standard inoculating solutions for application to hydroponic plant growth experiments.

Prepared and analyzed chemical inocula for use in lysimeter migration studies.

Performed microanalyses in support of chemical stability studies of organic compounds in soil.

Performed investigations of microbiological lipid characterizations including instrumental and radioisotopic techniques.

Perform routine quantitative chemical analyses on fumer mixes, black powder, and propellant samples.

PUBLICATION

Freeman, B.A., R. Sissenstein, T.T. McManus, J.E. Woodward, I.M. Lee, J.B. Mudd. "Lipid Composition and Lipids Metabolism of Spiroplasma Citri," Journal of Bacteriology, 125:3 (1976), pp. 946-954.

D. W. HUBER
Test Engineer
(Full Time Consultant)

EDUCATION

University of Maryland (Overseas Extension Division), 1958 to 1959.
Orange Coast College, 1956.
Santa Ana College, current.
U.S. Marine Corps Schools 1941 - 1956.

WORK HISTORY

1960 to date: AOMC. Test Engineer.

1940 to 1960: United States Marine Corps. Aviation Ordnance Chief.

EXPERIENCE

Test engineer on classified studies of several years duration relating to uptake of contaminant chemicals by plants grown in hydroponic culture. Also similar duties on projects involving both water and soil culture of plants.

Assigned for seven years as test engineer on experimental programs to study concepts and techniques for the generation and aerosolization of toxic chemical agents. Complete responsibility for scheduling and conducting dissemination tests on various prototype munitions. Duties include preparation of test devices, observation of test, recording of pertinent test data, and assistance in evaluation of data. Other duties include supervision of test personnel and responsibility for expediting facility maintenance to ensure meeting test schedules.

Previously acted as test engineer on a study of hypervelocity projectiles propelled by a light gas gun and a study on the damage to metal structures by hypervelocity projectiles.

Ordnance Chief over operations using napalm, pyrotechnic, and smoke devices. Chief of assembly team on special weapons, mechanical assembly surveillance, and storage of special weapons.

Assigned, trained and supervised avaiation ordnance personnel in handling and use of all types of ordnance items.

Tested and inspected aircraft ordnance systems. Maintained ordnance supplies, assembled munitions and fuzes. Operated rockets, rocket launchers, and fire control systems.

H. D. CHAPMAN
Soil Consultant

EDUCATION

Ph.D., Soil Chemistry, University of Wisconsin, 1927.

WORK HISTORY

1961 to Present: University of California, Riverside, Department of Soils and Plant Nutrition, UC Citrus Research Center and Agricultural Experiment Station. Professor of Soils and Plant Nutrition and Chemist (Emeritus).

EXPERIENCE

A brief summary of Dr. Chapman's experience is as follows:

- Assistant Chemist, University of California, Riverside, 1927; Associate Chemist, 1938; Chemist and Professor, Soils and Plant Nutrition, 1944; Chairman, Department of Soils and Plant Nutrition, 1938 to 1961.

- Director, University of California Citrus Experiment Station, Riverside, March 1, 1951, to January 31, 1952, during special leaves of past and newly appointed director.

- Assistant in Soils, University of Wisconsin, November 1925 to September 1927.

- Industrial Fellowship in Soils, University of Wisconsin, March 1925 to October 1925 (research).

J. P. MARTIN
Soil Consultant

EDUCATION

Ph. D., Soil Microbiology, Rutgers University, 1941.

WORK HISTORY

1945 to date: University of California, Riverside, Department of Soils and Plant Nutrition, UC Citrus Research Center and Agricultural Experiment Station. Present Position: Professor of Soil Sciences and Vice-Chairman of the Department of Soils and Plant Nutrition.

EXPERIENCE

Dr. Martin's research on soil microbiology and other complementary aspects of soil sicence have gained him national and international recognition.

He has been a pioneer in research on the microbial and fungal synthesis of polysaccharides and polyphenolic substances that occur widely in soils and have important effects on soil chemical and physical properties. His extensive contributions in this area have included work on mechanisms of synthesis, the chemical compositions, constituent units and functional groups of the polymers produced by soil microorganisms, and work on their aggregating effects and persistence in soil. Recent findings on the production and makeup of humic acid provide new information on the chemical nature of this important class of substances and knowledge of how they are formed.

MASARU NISHIBAYASHI
Senior Chemistry Specialist

EDUCATION

B.S., Chemistry, University of Cincinnati, 1949.
Ph. D., Physical Chemistry, University of Cincinnati, 1953.
Research Fellow, University of Cincinnati, 1950.

WORK HISTORY

1953 to date: AOMC. Research Chemist and Senior Chemistry Specialist.

EXPERIENCE

Development and conductance of analytical procedures with the gas chromatograph for various chemical compounds related to toxic materials.

Development of analytical techniques for propellants, propellant ingredients, and combustion products of propellants.

Analyses of gaseous products evolved during storage of various propellants.

Determination of physical and chemical properties of propellants.

Project Engineer for 3 years on 27mm semitelescoped caseless ammunition.

Development and characterization of high burning rate, castible double-base propellants for caseless ammunition.

Responsible for programs involving the development and characterization of light-initiable explosives.

Studies of the explosive hazards of solid propellants; studies of phenomena associated with the mixing of cryogenic propellants; kinetic studies related to investigation of detonability of high-energy propellants.

Photographic studies of rocket exhaust flames to determine characteristics of various rocket systems.

Studied use of additives for monopropellants to obtain desirable burning characteristics.

Studied ignition of monopropellant vapors in various atmospheres at varying temperatures.

PUBLICATIONS

Determination of Water, Methyl Hydrazines, and Related Compounds by Gas-Liquid Chromatography. Presented at National ACS meeting, Boston, April 1959.

MEMBERSHIPS

American Chemical Society
Phi Lamba Upsilon
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Combustion Institute
American Institute of Aeronautics and Astronautics